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A Comparison of Spatial & Frequency Domain Fusion Methods

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Abstract: ***The main application of image fusion is merging the gray level high resolution image and results in a new image that retains the most desirable information and characteristics of each source image. Since the idea of image fusion proposed, numbers of algorithms have been developed. It has been found that standard fusion methods usually introduce distortion. To overcome this problem multi scale transform based fusion methods have been proposed. This paper mainly concentrate on the comparison of different spatial and frequency domain image fusion methods based on performance parameters and gives the results for different algorithms in order to find out a better algorithm in most evaluation indexes.***

Keywords: PCA, Wavelet transform, Pixel level fusion, evaluation parameters

1. Introduction

The language of an image is universal. Images were means of communicating information in ancient days. Even today, although people from different parts of the world speak in different languages, an image conveys almost the same universal meaning to all. With the rapid development of modern computer technologies and with the increasing attempt in getting information at once fingertips, the importance of communication of information using cannot be ignored[1] . Image processing is a method to convert an image into digital form and perform some operations on it, in order to get an enhanced image or to extract some useful information from it. The simplest image fusion methods just average all of the source images pixel-by-pixel at gray level. This often leads to undesirable side effects such as reduced contrast and blurry edge . Another effective method is block-based method, this method divided images into small blocks, extracted clear blocks and reconstructed the fused image from these clear blocks. The key step of this method is how to choose the clear blocks according to some criteria[10]. Various methods based on the multi-scale transforms have been proposed[4]. The basic idea is to perform a multi-scale decomposition on each source image, then integrate these decomposition coefficient to form a composite representation, and finally the fused image is reconstructed by performing an inverse transformation [4] .

Multi focus image fusion methods are of two types: Spatial domain and Frequency domain. Pixel based method is one type of the spatial domain method. Spatial domain work on pixels. In pixel based we directly deal with the image pixels. The pixel values are manipulated to achieve desired result. It is very simple method. But It can snot provide accurate result. Output is depend on image pixel only. In pixel based method we are mainly deals with the pixels. The pixel based method is mainly divided in 3 types as averaging, minimum and maximum. In frequency domain methods the image is first transferred in to frequency domain. It means that the Fourier Transform of the image is computed first.All the Fusion operations are performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get the resultant image. Frequency domain method gives accurate result compare to spatial methods.

2. Spatial Domain Methods

2.1 Averaging Method

This is the simplest approach, wherein, intensity of the output pixel is the average intensity of all the corresponding pixels from the input images. Due to the averaging operation, both the good and the bad information are minimized, arriving at a mean image. Performance of this method is not as promising as it will miss out most important details from the input images. The averaging method can be calculated by: $I_f(x_{HH},y) = [I_1 (x,y) + I_2 (x,y)] / 2$ ...(1)

2.2 Select Minimum Method

In this method, the pixel with maximum intensity from the corresponding spatial locations from all the images to be fused is selected as the resultant pixel of the fused output image. The advantage of this method over averaging method is that there is no compromise made over the good information available in the input images. But the disadvantage is that it considers only the higher pixel intensity as the better information ignoring all other values.

2.3 Select Maximum Method

This is similar to the select maximum method but with the difference, it considers only the pixel with lowest intensity value and ignores all other values. This method also has the disadvantage of either completely considering information or discarding it fully. Authors suggested that the images with dark shades would generate a good fused image with this method.

3. Frequency Domain Methods

3.1 Discrete Wavelet Transform

Wavelet transforms are linear transforms whose basis functions are called wavelets. The wavelets used in image fusion can be classified into many categories such as orthogonal, bi-orthogonal etc. These wavelets share some common properties, each wavelet has a unique image decomposition & reconstruction methods that leads to different fusion results.

3.1.1 Image Decomposition

The DWT can be interpreted as signal decomposition in a set of independent, spatially oriented frequency channels. The signal S is passed through two complementary filters and emerges as two signals, approximation and Details. This is called decomposition or analysis. Wavelet separately filters and down samples the 2-D data (image) in the vertical and horizontal directions. The input (source) image is I(x, y) filtered by low pass filter L and high pass filter H in horizontal direction and then down sampled by a factor of two (keeping the alternative sample) to create the coefficient matrices $I_L(x,y)$ and $I_H(x,y)$. The coefficient matrix $I_L(x,y)$ and $I_H(x,y)$ are both low pass and high pass filtered in vertical direction and down sampled by a factor of two to create sub bands (sub images) $I_{LL}(x,y)$, $I_{LH}(x,y)$, $I_{HL}(x,y)$, I (x,y)[3] .

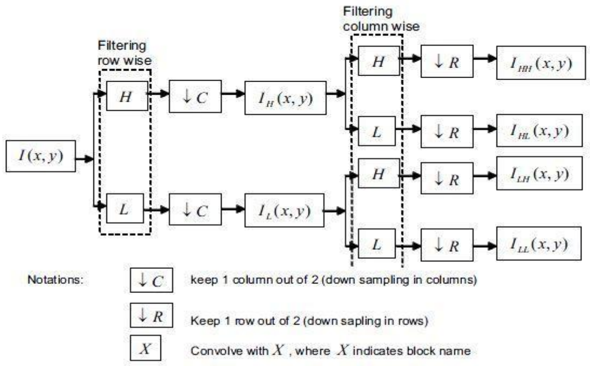


Figure 1: One Level Of 2-D Image Decomposition

The $I_{LL}(x,y)$, contains the average image information corresponding to low frequency band of multi scale decomposition. It could be considered as smoothed and sub sampled version of the source image I(x,y). $I_{LH}(x,y)$, $I_{HL}(x,y)$. and $I_{HH}(x,y)$ contains directional (vertical, horizontal and diagonal) information of the source image I(x,y),

3.1.2 Image Reconstruction

The information flow in one level of 2-D image reconstruction is illustrated in figure 2. Inverse 2-D wavelet transform is used to reconstruct the image I (x,y), from sub images $I_{LL}(x,y)$, $I_{LH}(x,y)$, $L_{HL}(x,y)$, and $L_{HH}(x,y)$. This involves column up sampling (inserting zeros between samples) and filtering using low pass L and high pass filter H for each sub images. Row up sampling and filtering with low

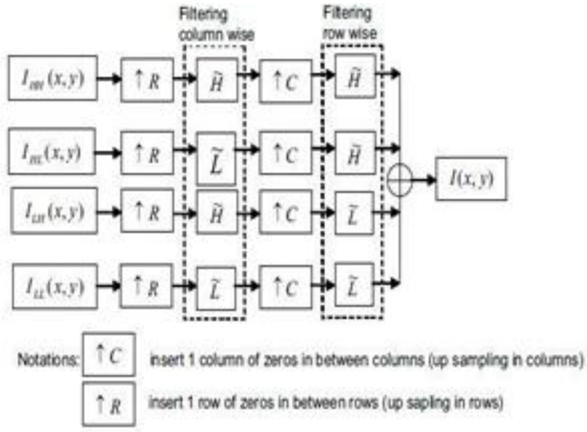


Figure 2: One Level Of 2-D Image Reconstruction

pass filter L and high pass filter H of the resulting image and summation of all matrices would construct the image I(x, y).

3.1.3 Block Diagram of DWT

The figure 3 shows the main blocks and flow of fusion process using DWT. First consider two registered input image I_1 and I_2 which are too be fused. Then apply DWT to both *I1* and *I2*, and their coefficients in pixel *p* are $D_{I1}(p)$ and $D_{I2}(p)$, respectively. The output DWT coefficient in pixel *p* is D_{I3} (p) given by using "choose-max" selection rule i.e. choosing maximum DWT coefficient between I_1 and I_2. After that Perform Inverse DWT to D_{I3}. Finally, the fused image is displayed. The fusion rule used in this paper is simply averages the approximation coefficients and picks the detailed coefficients in each sub band with the largest magnitude.

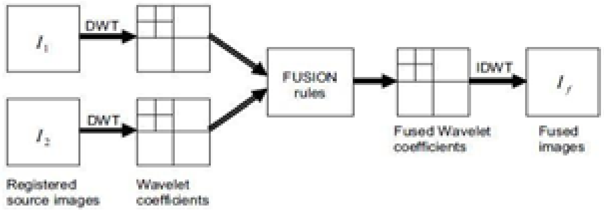


Figure 3: Flow Diagram of DWT

3.2 Principal Component Analysis

PCA transformation [3] is a statistical method. It transforms a group of related variables into a group of the original variables. The aim is to compress multi-band image information into an image and information can perform maximum in the new image. During the fusion process, it first carries on PCA transformation so that the gray scale mean and variance are consistent with PCA component of the image.PCA is the simplest true eigenvector-based multivariate analysis. It involves ways for identifying and to show patterns in data, in such a way as to highlight their similarities and differences, and thus reduce dimension without loss of data. In this method first the column vectors are extracted, from respective input image matrices. The covariance matrix is calculated. Diagonal elements of covariance vector will contain variance of each column vector. The Eigen values and the vectors of covariance matrix are calculated. Normalize column vector corresponding to larger Eigen value by dividing each element with mean of Eigen vector. Those normalized Eigen vector values act as the weight values and are multiplied with each pixel of input image. Sum of the two scaled matrices are calculated and it will be the fused image matrix.

The information flow diagram of PCA-based image fusion algorithm is shown in figure 4. The input images (images to be fused) I1(x, y) and I2(x, y) are arranged in two column vectors and their empirical means are subtracted. The resulting vector has a dimension of n x 2, where n is length of the each image vector. Compute the eigenvector and eigen values for this resulting vector are computed and the eigenvectors corresponding to the larger eigen value obtained[7].The fused image is:

$I_f(x,y) = P_1I_1(x,y) + P_2I_2(x,y)$ ...(2)

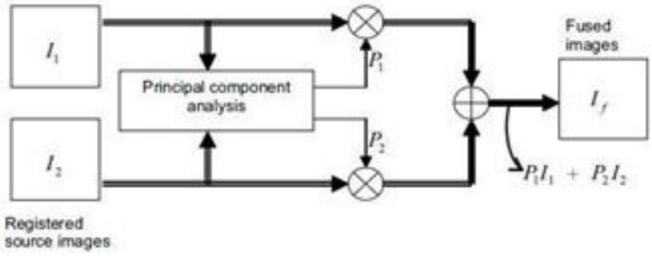


Figure 4: Flow Diagram of PCA

4. Performance Evaluation

Performance evaluation is an essential part of Image fusion processing so one can further adjust the algorithm parameter through analyzing, testing and evaluating the effects of the fusion algorithm and performance so the whole fusion process can be optimized. Performance parameters are of two types: with reference image and without reference image.

4.1 Without Reference Image

When the reference image is not available then the performance of the image fusion algorithms cab be evaluated using following metrics:

Information Entropy: Entropy is used to evaluate the information quantity contained in an image. If entropy of fused image is high, it indicates that the fused image contains more information. Entropy is defined as

$$E = -\sum_{i=0}^{l-1} p_i \log_2 p_i \quad ...(3)$$

Where L is the number of pixel levels in the fused image. Pi is probability of occurrence of a particular gray level i. Entropy can directly reflect the average information content of an image.

Standard Deviation: Degree of dispersion between the value Of each Pixel and the average value of image. Standard Deviation can be find using following formula:

$$\sigma = \sqrt{\sum_{i=0}^{L}(i-\bar{i})^2 h_{I_f}(i)},\ \bar{i} = \sum_{i=0}^{L} i h_{I_f} \quad ...(4)$$

Maximum the standard deviation gives better resultant image.

Mean : The mean value of an image with the size of m×n is defined as

$$\hat{\mu} = \frac{1}{n\times n}\sum_{j=1}^{n}\sum_{i=1}^{m} x_{i,j} \quad ...(5)$$

where $x_{i,j}$ denotes the gray level of a pixel with coordinate (i, j).

The mean value represents the average intensity of an image. Higher the mean value better the image quality.

4.2 With Reference Image

When the reference image is not available then the performance of the image fusion algorithms cab be evaluated using following metrics:

Mean Square Error: The MSE represent the cumulative squared error between the original image and reconstructed image. The lower the value of MSE, the error may be lower.

$$MSE = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I_r(i,j) - I_f(i,j)\right)^2} \quad ..(6)$$

Peak Signal To Noise Ratio : PSNR used for quality measurement ratio between original image and reconstructed image. The higher the PSNR, the better the quality of the reconstructed image.

$$PSNR = 20\log_{10}\left(\frac{L^2}{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I_r(i,j)-I_f(i,j)\right)^2}\right) \quad ...(7)$$

4.3 Results and Comparative Analysis

In table 1, we have compared a variety of the parameters of fusion methods. In figure 5 fused image using different algorithms are shown.

5. Conclusion

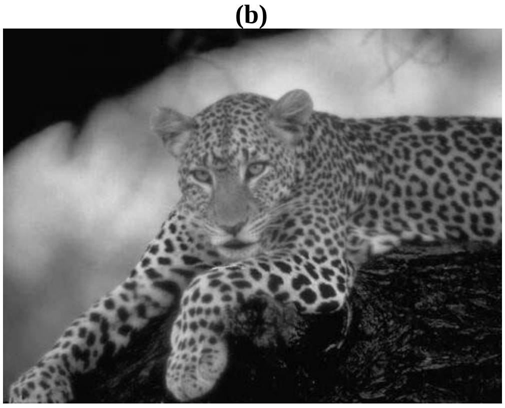
From the above table 1, we conclude that simple pixel methods gives poor result in fused image. PCA belongs to component replacement method and disadvantage is that it gives distort multi spectral characteristics of original image. From figure 5 and table 1 we can conclude that performance parameters for DWT are having higher value than other methods. So DWT gives more information content, high quality and better resultant fused image.

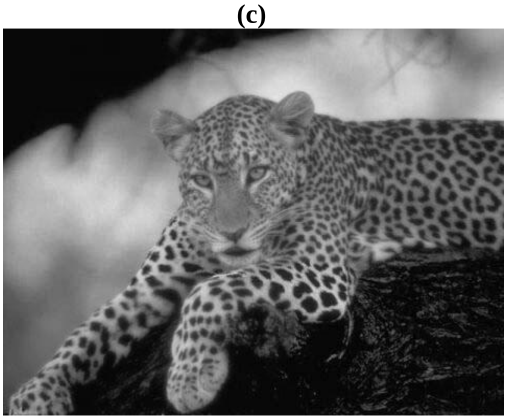
Table 1: Comparative Analysis

Fusion Methods	Entropy	Standard Deviation	Mean	PSNR
Pixel Averaging	7.4085	63.9531	92.1967	49.5116
Pixel Minimum	7.3978	63.7820	88.5469	49.5154
DWT	7.4196	64.9531	95.5751	49.5352
Pixel Maximum	7.4163	64.6261	95.5941	49.5324
PCA	7.4072	63.9570	92.0713	49.5087


(a)


(b)


(c)


(d)


(e)


(f)


(g)

Figure 5: (a) Input Image 1 (b) Input Image 2 (c) Fused Image Using Averaging Approach (d) Fused image using PCA approach (e) Fused image using pixel maximum approach (f) Fused image using pixel minimum approach (g) Fused image using DWT approach.

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