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Basic Medical Image Fusion Methods

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***Abstract*—Medical image fusion is the process of combining two or more images of the same scene, from the single or multiple imaging modalities, to obtain the image which preserves important features from each. Different medical imaging modalities used in fusion are Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and Single-Photon Emission Computed Tomography (SPECT). Image fusion techniques are broadly classified into two categories; spatial domain image fusion (pixel level) and transform domain image fusion. The basic spatial domain image fusion methods are Simple Average, Select maximum, Select Minimum, Principal Component Analysis (PCA), Intensity-Hue-Saturation (IHS) transform, and Singular Value Decomposition (SVD) etc. Examples for transform domain image fusion methods are Pyramid Fusion Algorithms, Discrete Wavelet Transform (DWT), DT-CWT, Stationary Wavelet Transform (SWT), and Curvelet Transform etc. The image fusion can be performed at different levels such as pixel, feature, signal, and decision level. In this paper image fusion methods such as Simple Average, Select maximum, Select Minimum, Principal Component Analysis (PCA), and Discrete Wavelet Transform (DWT) are explained and are compared using the quality metrics Peak Signal to Noise Ratio (PSNR) and Root Mean Square Error (RMSE).**

Keywords—Image Fusion; PCA; DWT; Quality metrics.

I. INTRODUCTION

The imaging modalities used in medical image fusion are CT, MRI, PET, and SPECT etc. In which MRI and CT are structural imaging modalities. PET and SPECT are functional imaging modalities. MRI and CT produces high spatial resolution images with only anatomical information and no functional information. Whereas, PET and SPECT produces functional images with low spatial resolution. Goal of the image fusion is to obtain both structural and functional information in the single image. With the use of anatomical image, a tumor or any abnormalities in the tissue of an organ can be easily detected. On the contrary, with the functional images this is not possible. But, the functional images have the ability to detect lesions before the anatomy is damaged. So the fusion of structural and functional images could avoid undesirable effects.

II. PRE-PROCESSING STEPS IN IMAGE FUSION

Two images taken at different angles of the same scene , or different times from different sensors, or from different viewpoints sometimes causes distortion. So before fusing the images, we have to make sure that both the images are spatially aligned and have the same dimensions. The basic steps used in image fusion are, given in Fig.1 below.

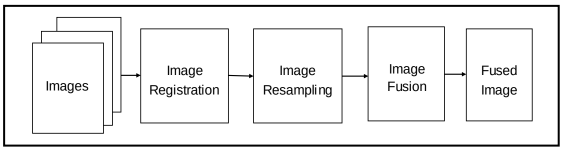

Fig. 1. Pre-processing of image fusion.

Image Registration

Image registration transforms different set of data into one coordinate system. Image registration or image alignment algorithms can be classified into intensity-based and feature-based registration. One of the images is referred to as the source image and the others are respectively referred to as the target images.

Intensity-based method uses correlation metrics to compare intensity patterns in the images. While feature-based method compare the features such as points, lines, and contours in the images to be registered.

Image Resampling

Image resampling is the process of changing the pixel dimension of an image. For performing image fusion images should have same pixel dimensions. Resampling changes the image dimension, so that the images to be fused will be of same dimension. Downsampling an image means that information is deleted from the image. Similarly upsampling an image means that new pixels are added based on color and intensity values of existing pixels. Image resampling can be performed by using the methods such as nearest neighbor, bilinear, and bicubic (cubic convolution).

III. IMAGE FUSION TECHNIQUES

The following image fusion techniques are explained in this paper:

1. Simple Average Method.
2. Select Maximum Method.
3. Select Minimum Method.
4. Principal Component Analysis (PCA) Method and,
5. Discrete Wavelet Transform (DWT) method.

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A. Simple Average method

Simple average algorithm is very easy to understand and implement. When input images to be fused are from same type of sensor and have an overall high brightness and high contrast, simple average method can be used. This method obtains the output image with all regions in focus. Since average of the pixels of the two input images are performed.

Pixel value of each image is taken and added. Then divided by the number of input images to obtain the average value. This average value obtained is then assigned to the corresponding pixel of the output image. This will be repeated for all pixel values of the input images to be fused.

$$O(x,y) = \frac{\left(A_1(x,y) + A_2(x,y) + \cdots + A_n(x,y)\right)}{n} \quad (1)$$

where $A_1(x,y)$, $A_2(x,y)$,……,$A_n(x,y)$ are input images and $'n'$ is total number of input images, and $O(x,y)$ is the output image.

Disadvantage of this method is that both good and bad information are minimized, resulting in an average image. Because of this important details will miss out from the input images.

B. Select Maximum Method

Select maximum method selects pixel with highest pixel intensity among the input images. Selected highest pixel values from input images are assigned to the corresponding pixel values of the output image. For example, if we have two input images A_1 and A_2, first we need to compare pixels $A_1(x,y)$ and $A_2(x,y)$. Then pixel with highest pixel intensity is selected and then assigned to the corresponding pixel value of the output image.

$$if\ A_1(x,y) \geq A_2(x,y) \quad (2)$$

$$O(x,y) = A_1(x,y)$$

else

$$O(x,y) = A_2(x,y)$$

where $A_1(x,y)$ and $A_2(x,y)$ are input images and $O(x,y)$ is the fused image.

This method produces highly focused output image when compared to simple average method. But it considers only the highest pixel intensity, ignoring lower pixel values.

C. Select Minimum Method

This method is similar to select maximum method. But the only difference is, it considers only the pixel with lowest pixel intensity values and ignores other pixel values. When the input images have low brightness this method can be used.

D. Principal Component Analysis

Principal Component analysis (PCA) is also known as Karhunen-Loeve Transform or the Hotelling Transform. It transforms number of correlated variable in to number of uncorrelated variable. These uncorrelated variables are called principal components. This property of the PCA is used in image fusion. The PCA is used to reduce the dimensionality of the input data set with very less loss of data.

Steps involved in PCA algorithm are:

1. The two images to be fused are arranged in two column vectors.
2. Perform the empirical mean along each column.
3. Next we need to subtract empirical mean from each column of the data matrix respectively.
4. The covariance matrix $'C'$ is obtained from the mean subtracted data matrix. It will be of dimension 2×2.
5. Obtain the eigenvalues $'D'$ and eigenvectors $'V'$ from the covariance matrix and sort them by decreasing eigenvalues. The resulting matrix is of dimension 2×2.
6. Then compute normalized components by using,
$$P_1 = \frac{v(1)}{\sum v(1)} \quad \& \quad P_2 = \frac{v(2)}{\sum v(2)} \quad (3)$$
7. The fused image is obtained by,
$$I_f(x,y) = P_1 I_1(x,y) + P_2 I_2(x,y) \quad (4)$$

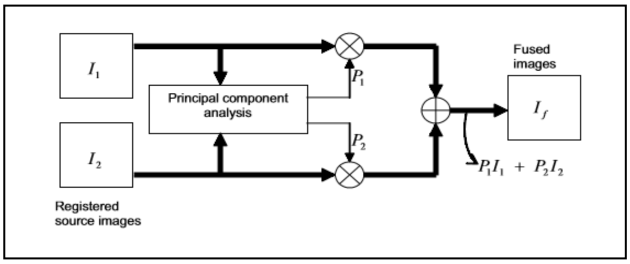

Fig. 2. Block diagram for image fusion scheme employing PCA.

The PCA produces the fused image with high spatial quality. But it causes spectral degradation in the fused image.

E. Discreate Wavelet Transform Method

Wavelets are finite duration and finite energy oscillatory functions with zero average value. Wavelets can be defined using two functions namely; father wavelet or scaling function and mother wavelet or wavelet function.

The DWT provides a flexible multi-resolution analysis of an image. According to wavelet theory, the scaling function is implemented as low-pass filter (LPF) and mother wavelet is implemented as high-pass filter (HPF). For computing 2-D DWT, first we need to perform 1-D DWT on the rows of the input image matrix and then columns of the matrix by separately filtering and down sampling. This results in 4 set of coefficients. In which one is approaximation coefficient (LL) and three detail coefficients (LH – Horizontal, HL – Vertical, and HH – Diagonal).

Steps in DWT are:

1. Perform image registration to both panchromatic (PAN) and multispectral (MS) image, and resample MS image.
2. Apply DWT to both PAN and MS image.
3. Fuse corresponding band coefficients of both images using average method.
4. Perform inverse DWT on the fused coefficients to obtain fused image.

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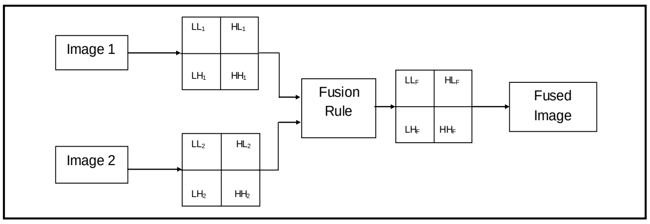

Fig. 3. Block diagram for DWT based image fusion

DWT method produces better spectral quality in the output fused image and also better PSNR. When compared to the pixel based method. But the spatial resolution of the output image is less.

IV. PERFORMANCE MEASURES

Quality metrics are used to measure the degradation of information when image fusion is performed. Based on the availability of reference image, the quality metrics are classified into referential and non-referential metrics. If the reference image is available, then comparison is made between fused image and known reference image. When the reference image is not available, the caparison is made between the fused image and the input images.

A. Root Mean Square Error(RMSE)

Root Mean Square Error (RMSE) is the measure of square of the difference between the pixel value of the fused image and the pixel value of the reference image, summing those together, dividing that by number of pixels in the image and then taking the square root of that result.

The Mathematical expansion for RMSE is given by,

$$RMSE = \sqrt{1/MN(\sum_{i=1}^{M}\sum_{j=1}^{N}\left(R(i,\ j) - F(i,\ j)\right)^2)} \qquad (5)$$

where $R(i,\ j)$ and $F(i,\ j)$ are the reference and fused images respectively, $'M'$ and $'N'$ are image dimensions. Fusion algorithm is said to be better if the RMSE value is smaller.

B. Peak Signal to Noise Ratio (PSNR)

It is the ratio between the maximum power of a signal and the power of corrupting noise, in decibels, between two images.

The mathematical expansion for PSNR is given by,

$$PSNR = 10log_{10}\left[\frac{N^2}{MSE\,(R,F)}\right] \qquad (6)$$

where $R(i,\ j)$ and $F(i,\ j)$ are reference and fused images respectively and $'N'$ represents the maximum value of the pixel in an image. The higher the PSNR, the better is the fusion algorithm.

V. RESULTS AND DISCUSSION

The Magnetic Resonance Inage (MRI) and Positron Emission Tomography (PET) images of brain are fused using above discussed techniques. Fig. 4(a) & 4(b) shows the two input images and Fig. 5(a) through 5(e) shows the fused output images of above discussed techniques respectively.

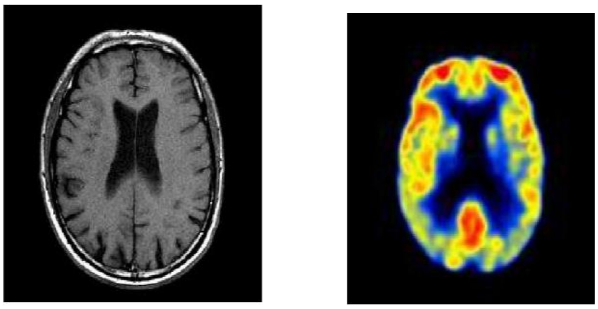

Fig. 4(a). Input Magnetic Resonance(MRI) image and 4(b) Input PositronEmission Tomography (PET) image

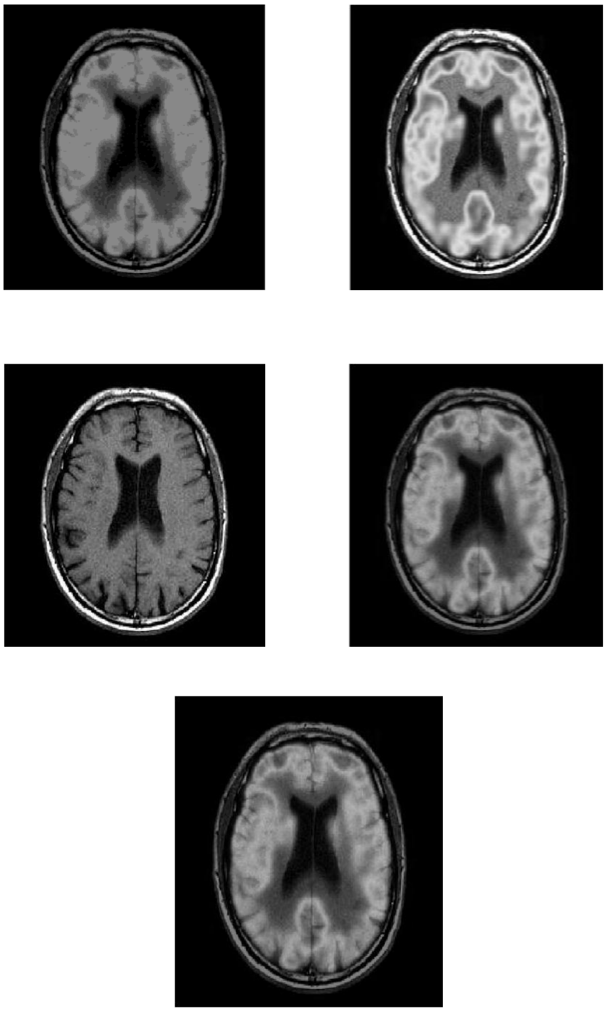

Fig. 5. Fused images using 5(a) Simple Average, 5(b) Select maximum method, 5(c) Select minimum method, 5(d) PCA method, and 5(e) DWT method.

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TABLE. 1 STATISTICAL ANALYSIS OF MEDICAL IMAGE FUSION TECHNIQUES

Fusion Method	**Metrics**	
	RMSE	PSNR(dB)
Simple Average Method	57.4253	12.9487
Select Maximum Method	43.5992	15.3944
Select Minimum Method	42.5992	14.3944
PCA Method	30.8915	18.3684
DWT method	28.7338	18.9629

From table.1 it is observed that the Simple Average method has higher RMSE and lower PSNR. DWT has higher PSNR and lower RMSE, when compared to all other fusion techniques.

VI. CONCLUSION

The input medical images are fused using Simple Average, Select maximum, Select Minimum, Principal Component Analysis (PCA), and Discrete Wavelet Transform (DWT) method. DWT method gives higher PSNR and lower RMSE value. Simple Average method gives lower PSNR and higher RMSE value. DWT method gives the output image with higher spectral quality when compare to all other methods.

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