Asian Journal of Convergence in Technology *Volume II, Issue III*
Issn No.:2350-1146, I.F-2.71

Image Fusion Methods for Medical and General Purpose Applications

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***Abstract* - The image fusion is used to combine the complementary information from multiple images of the same scene into a single image which includes more information than rest of the input images. In situations where spatial and spectral information is required in a single image such as in medical imaging, remote sensing, digital camera; image fusion is necessary. Images are fused by Spatial domain & Transform domain methods. Quality of fused images is assessed by several quality metrics.**

Index Terms - Image fusion, Spatial domain, transform domain, Quality metrics

I. Introduction

Image fusion fuses relative information from multiple images of the same scene into a single image. The resultant image carries more information than rest of the input images. Image fusion has wide areas of applications in medical, digital camera and remote sensing. Different medical imaging techniques such as MRI, PET, CT are used in medical applications [3]. By fusing different images more precise diagnosis information will be obtained. PET is a functional image showing brain activity without anatomical information whereas MRI provides anatomical information without functional activity. Space resolution of PET image is lower than the MRI image. So both these images are fused to obtain a unique image with functional and anatomical information and with the best resolution [2]. Image fusion is also used in multi-focus image application to enhance multiple camera images. Sometimes it is not possible to get an image that contains all relevant objects in focus due to limited depth-of-focus of optical lenses. To overcome this, several images with different focus points are taken. These images are combined to obtain composite image.

Images are fused by spatial domain and transform domain methods. Spatial domain methods are simple but produce spatial distortion & reduced contrast in the fused image. Drawbacks in spatial domain methods can be overcome by using transform domain methods. Transform domain methods are divided into pyramid transform & Discrete Wavelet Transform (DWT).The general requirement of image fusing is that, it should preserved all valid & pattern information from input images simultaneously, it should not introduce any artifact which could distract the observer. So quality assessment of fused image is important. Entropy, mutual information, RMSE, standard deviation are the quality metrics used to evaluate performance of image fusion methods.

II. Image Fusion Methods

Image fusion methods are classified as spatial domain methods and transform domain methods.

A. Spatial domain methods

Spatial domain methods are averaging, maximum selection method & Principal Component Analysis (PCA). Averaging method is simplest method but has less contrast & loss of information is more as compared to other methods. The value of the pixel P (i,j) of each image is taken and added. This sum is then divided by N to obtain the average. The average value is assigned to the corresponding pixel of the output image. Averaging method shows better performance when input images are of same modalities. In maximum selection method, maximum pixel intensity value is selected. It shows better performance when input images are of different modalities.

Principal Component Analysis (PCA) [5] is an orthogonal transformation that transforms large number of correlated variables into small number of uncorrelated variables. This PCA transformation generates new co-ordinate system. The greatest variance by any projection of data lies in the first co-ordinate which is known as the principal component. The second greater variance on the second co-ordinate and so on. This is simple method, having less spatial distortion.

B. Transform domain methods

Transform domain approach is multi-resolution approach. In this method, a multi-resolution decomposition is performed on each source image. Then all these decompositions are integrated to form a composite representation. Finally fused image is reconstructed by performing an inverse multi-resolution transform. It involves two methods pyramid and wavelet transform.

1. Pyramid transform

An image pyramid consists of a set of low pass or band-pass copies of an image. Pattern information of each copy is represented on different scale. The pyramid transform of the fused image is constructed from the pyramid transforms of the source images. By taking inverse pyramid transform, fused image is obtained. Pyramid transform consists of three major phases: Decomposition, Formation of image, Re-composition.

-Decomposition: Decomposition is the process where a pyramid is generated successively at each level of the fusion. It consists of low pass filtering of an image followed by decimation.
-Formation of image: Merging the input images is performed after the decomposition process. This resultant image matrix would act as the initial input to the re-composition process.
-Re-composition: Re-composition is the process wherein the resultant image is finally developed from the pyramids formed at each level of decomposition. It consists of un-decimation & low pass filtering of an image.

The process of pyramid transform with example is described in Fig.1

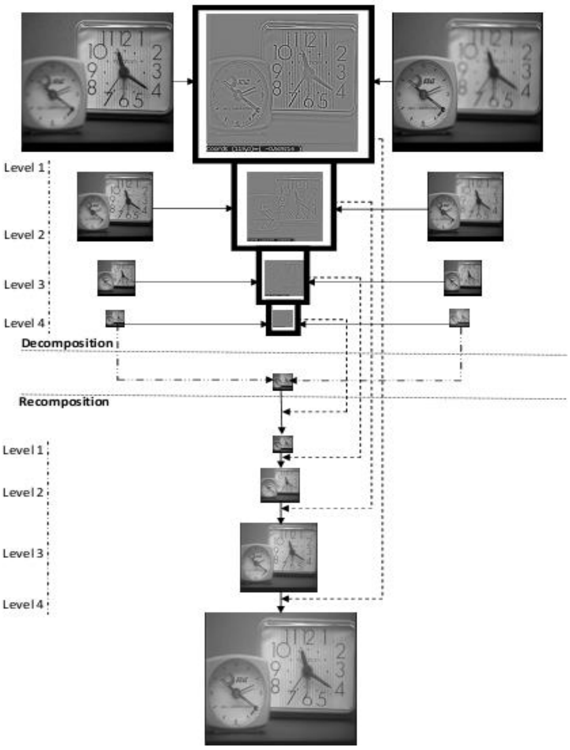

Fig. 1 Fusion using pyramid transform

Image pyramids are classified as Laplacian Pyramid, Ratio Pyramid, Filter Substrate Decimate (FSD) pyramid [8]

i. Laplacian Pyramid method

In laplacian pyramid fusion, laplacian pyramid of input images are used. Laplacian pyramid of an image consists of set of band-pass images. Each image is a band-pass filtered copy of its previous image. Band-pass copies can be obtained by calculating the difference between low pass images at successive levels of a Gaussian pyramid. Gaussian pyramid is set of images. Each image is low pass filtered copy of its previous image. Pyramid decomposition of an image is shown in Fig.2.

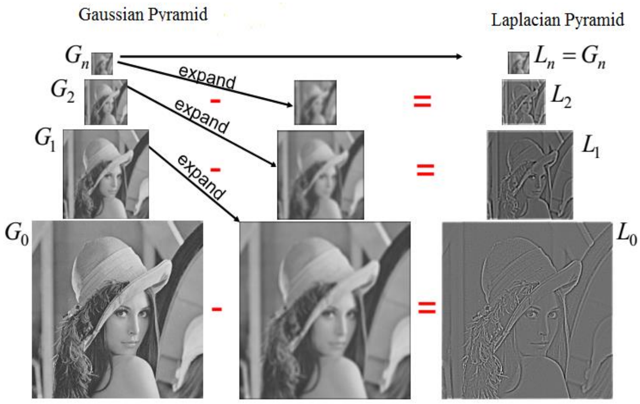

Fig. 2 Laplacian pyramid decomposition

ii. Filter-Subtract-decimate (FSD) Pyramid

FSD pyramid fusion is similar to Laplacian fusion but the difference is instead of using Laplacian pyramid, FSD pyramid of an image is used. Pyramid is formed by subtracting low pass filtered input images. This method is computationally more efficient than laplacian pyramid method.

iii. Contrast Pyramid /Ratio of Low Pass Pyramid (ROLP)

Every level of ROLP is ratio of two successive levels of Gaussian pyramid. The composite image produced by this method preserve details that are most relevant to visual perception.

2. Wavelet Transform

The wavelet transform allows multi-resolution analysis of an image. It manages images of different resolutions. Discrete wavelets transform (DWT) decomposed the image in different kinds of coefficients that stores the image information.

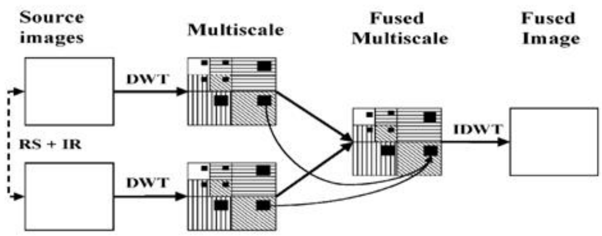

Fig. 3 Image fusion using Wavelet transform

Fig. 3 shows image fusion scheme using wavelet transform [2]. The DWT is applied on input images and decomposition of each input image is achieved. This is multiscale image where different bars (horizontal, vertical, diagonal and null) represent different coefficients. The different black boxes present in each decomposition level, are coefficients having the same image representation as original image [6]. Only coefficients of the same level and representation are fused as shown in Fig.3, where the merged coefficients are indicated by curved arrows. This is nothing but fused multiscale. IDWT is applied on fused multiscale to obtain final fused image.

III. Quality Metrics For Image Fusion

Image fusion algorithm may introduce some amounts of distortion in the signal, so the quality assessment is an important task [7]. To enhance quality of fusion methods, metrics are designed to facilitate the image fusion quality.

A. Entropy

Entropy of an image is defined as,

$$H = -\sum_{i=1}^{m} Pi\log_2 Pi \quad \ldots\ldots(1)$$

Where Pi is the ratio of number of pixels with gray scale (i) to the total number of pixels. Entropy represents the average information content of an image. If entropy of fused image is higher than input images then fused image contain more information.

B. Mutual Information

Mutual information measures the amount of information that the one variable contains about another [1]. MI represents the similarity of the image intensity distribution of the corresponding image pair. Let A & B be two random variables with marginal probability distribution P_A (a) and P_B (b),and joint probability distribution P_{AB} (a, b). It measures the degree of dependence of two random variables A and B and is given by kullback-Leibler measure

$$I_{AB}(a, b) = \sum_{x,y} P_{AB}(a, b) \log\frac{P_{AB}(a,b)}{P_A(a)P_B(b)} \quad \ldots\ldots(2)$$

Where P_{AB} (a, b) is joint distribution and $P_A(a).P_B(b)$ is the distribution associated with the case of complete independence

C. SSIM

Structural Similarity index (SSIM) measures the similarity between two images and it is given by [4]

$$SSIM(x,y|w) = \frac{(2\mu_x\mu_y+C_1)(2cov_{xy}+C2)}{(\mu_x^2+\mu_y^2+C1)(\sigma_x^2+\sigma_y^2+C2)} \quad .. \ (3)$$

Where, C1 and C2 are constants.

μx, μy are mean of x & y respectively.

σ_x^2 is variance of x and σ_y^2 is variance of y

Cov_{xy} is the covariance of x, y

SSIM is a measure of the similarity between the regions x and y. The range of SSIM is [-1, 1] and the value 1 is achieved if and only if x and y are the same.

D. Root Mean Square Error (RMSE)

Root mean square error indicates amount of deviation present in the fused image compared to reference image. Lower the value of RMSE better is the quality of fused image. It is defined as,

$$RMSE = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}|R(i,j)-F(i,j)|^2} \quad \ldots\ldots(4)$$

Where, R - Reference image, F - Fused image, i - Pixel row index, j – Pixel column index, M – No. of rows, N – No. Of columns.

E. Standard Deviation

Standard deviation measures the contrast in the fused image. An image with high contrast has high standard deviation. It is given by,

$$\sigma = \sqrt{\sum_{i=0}^{L}(i-\bar{i})^2 h_{1f}(i)} \quad \ldots\ldots(5)$$

$$\bar{i} = \sum_{i=0}^{L} i * h_{1f} \quad \ldots\ldots(6)$$

Where h_{1f} is normalized histogram of fused image and L is number of frequency bins in histogram.

IV. Results And Discussion

Pair of off focus images from camera of size 256×256 are taken as input images. Fusion is implemented on both images and fusion results are shown in Fig. 4. The results of image quality evaluation of the fused images by various algorithms are given in Table 1.

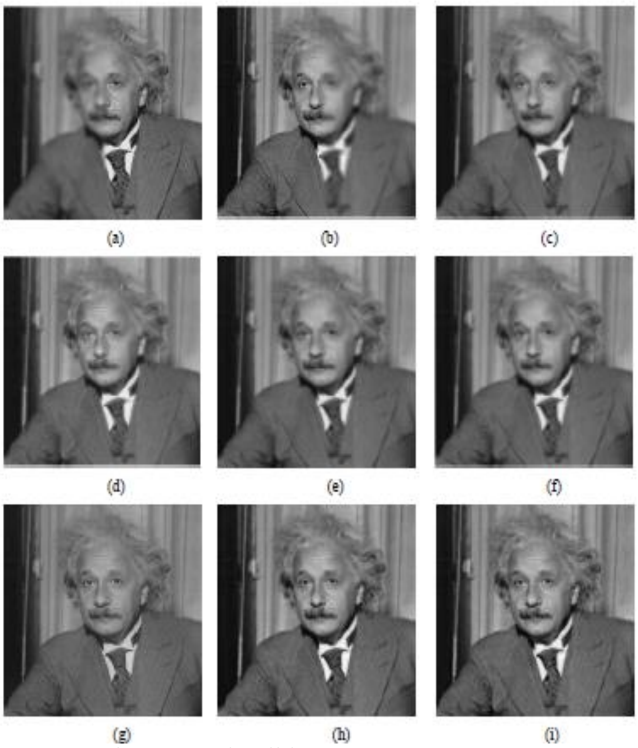

Fig. 4 Image fusion result for off-focus camera images a) Image 1, b) Image 2, c) Averaging, d) Maximum selection, e) PCA, f) Laplacian, g) FSD, h)Contrast, i)DWT

TABLE I
IMAGE QUALITY EVALUATION

Quality Metrics	Combination	Averaging	Maximum Selection	PCA	Laplacian Pyramid	FSD Pyramid	Contrast Pyramid	DWT
Entropy	Fused image	7.095	7.0878	7.1340	7.2318	7.0617	7.2322	7.2404
SSIM	A-Fused image	0.9256	0.9358	0.9772	0.9472	0.9981	0.9559	0.9618
	B-Fused image	0.9453	0.985	0.9824	0.9809	0.9732	0.9803	0.9784
Mutual Information	A-Fused image	2.485	2.4718	2.9121	2.7855	2.6421	2.7848	2.7159
	B-Fused image	2.6276	2.6541	3.0728	2.9402	2.632	2.9542	2.8099
RMSE	A-Fused image	15.6154	14.9848	8.8123	13.986	12.374	13.6537	13.823
	B- Fused image	13.9605	8.2057	8.0665	8.7	9.6272	8.8464	9.2319
Standard deviation	Fused image	40.3658	39.7605	40.365	44.7381	38.6588	40.4191	44.331

DWT method has highest entropy and averaging and maximum selection method has lowest entropy. PCA shows better performance for mutual information and RMSE metrics. Laplacian pyramid method has highest standard deviation i.e. high contrast, which can also be observed visually. DWT and PCA show comparable result for SSIM.

V. CONCLUSION

Spatial domain and transform domain fusion methods are implemented on medical imaging and off focus camera images. Different image fusion metrics with and without reference image have been evaluated. The simple averaging fusion algorithm show degraded performance for all set of images. Maximum selection also shows worst performance but has higher contrast as compared to other algorithms. Performance of PCA & DWT is better than other fusion methods.

VI. FUTURE SCOPE

Spatial domain & transform domain methods presented over here is a pixel-level approach. The same work can be easily extended further to other fusion-level schemes to combine aspects of pixel level and feature level fusion. Also more quality metrics can be developed to evaluate fused images.

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