COMPARATIVE STUDY OF IMAGE FUSION TECHNIQUES IN SPATIAL AND TRANSFORM DOMAIN

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ABSTRACT

The process by which different images or information from multiple images are combined is termed as Image fusion which is achieved by applying a sequence of operators on the images. Recently, a number of image fusion techniques have been developed. This paper presents a review on the main categories of image fusion namely spatial domain technique, transform domain technique and statistical domain fusion technique. Image Fusionis one of the latest fields adopted to solve the problems of digital image; image fusion produces high-quality images which contains additional information for the purposes of interpretation, classification, segmentation and compression, etc. The principle requirement of the fusion process is to identify the most significant features in the input images and to transfer them without loss of detail into the fused image. Image Fusion finds its application in vast range of areas. It is used for medical diagnostics and treatment. This paper presents a brief description of some of the extensively used image fusion techniques. Comparison of all available image fusion techniques concludes a better approach for future research on image fusion.

Keywords: spatial domain technique, transform domain technique, image fusion, segmentation, compression.

INTRODUCTION

A single image cannot depict the scene accurately in many situations. In such cases, the scene is usually captured using more than one sensor. Only a single image is more suitable for human or machine processing, hence it is important to fuse all the images from various sensors into a single composite image with all relevant information. Some of the major applications of image fusion include concealed weapon detection, medical diagnosis, target detection and recognition, military surveillance, remote sensing, navigation guidance for pilots, weather forecasting and so on. Image fusion algorithms are performed in four different categories namely signal level fusion algorithm, pixel level image fusion algorithm, feature level image fusion algorithm and decision level image fusion algorithm.

The main objective of image fusion is to facilitate better understanding of images and to introduce or enhance intelligence and system control functions. In signal based fusion, signals from various sensors are fused together to create a new signal, which has a better signal to noise ratio when compared to the original signal. Pixel level fusion is usually performed on the pixels of the source image. In feature level based fusion salient features such as pixel intensities, edges or textures are extracted. Information is merged at a higher level of abstraction in Decision level fusion. The results are combined from multiple algorithms to yield a final fused decision. Benefits of image fusion include an extended range of operations, extended spatial and temporal coverage, reduced uncertainty, increased reliability and robust system performance [3].

IMAGE FUSION ALGORITHMS

Fusion process is a combination of prominent information that have been brought together in order to synthesize an image. Several approaches to image fusion can be distinguished, depending on whether the images are fused in spatial domain or if they are transformed into another domain and later fused [1]. Image fusion algorithms are broadly grouped into 1. Spatial domain fusion 2. Transform domain fusion 3. Statistical domain fusion.

Spatial domain fusion technique uses local spatial features such as gradient, spatial frequency and local standard deviation [2]. The pixel values from two or more images are brought together and manipulated to obtain the desired results by spatial domain fusion technique. Some of the spatial domain techniques include *Averaging select maximum/minimum method, Bovey transforms, Intensity-hue-saturation method (IHS), High pass filtering method (HPF), Principal component analysis method (PCA).* Drawbacks of Spatial domain fusion include spectral degradation.

In Transform domain fusion the Fourier transform of the input image is computed first. Fusion operations are later performed on the Fourier transform of the image and then inverse Fourier transform is performed to obtain the resultant image. Some of the transform domain fusion techniques include *discrete wavelet transform, stationary wavelet transform.*

Statistical domain fusion utilizes statistical variables such as least squares, average of the local correlation or the variance with the average of the local correlation techniques to find the best fit. Statistical domain fusion is used to solve the two main problems that are caused in image fusion namely colour distortion and operator or dataset dependency. Some of the statistical domain fusion techniques include *Local Mean Matching (LMM), Local Mean and Variance Matching (LMVM), Regression Variable Substitution (RVS), Local Correlation Modeling (LCM)* [3].

It should be noted that traditional image fusion schemes often caused side effects such as reduced contrast since fusion was done directly on the source image and

thus transform domain fusion is performed to overcome contrast.

SPATIAL DOMAIN IMAGE FUSION TECHNIQUES

Pixel based Image Fusion

In pixel level image fusion, fusion is done on pixel basis. Let us consider two input images $I_1(x,y)$ and $I_2(x,y)$ that are required to be fused which are aligned in all aspects. Assume $I_f(x,y)$ be the fused output image. The process of combining $I_1(x,y)$ and $I_2(x,y)$ into $I_f(x,y)$ is called Image Fusion. Pixel intensities at every position of the input images (x,y) are averaged to obtain $I_f(x,y)$ pixel intensity of the fused image.

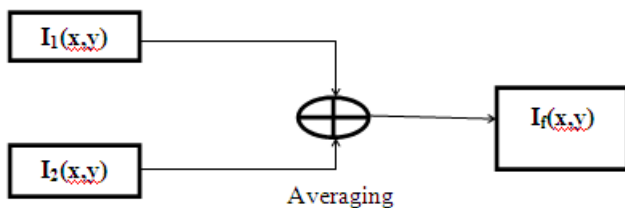Information flow diagram of pixel based image fusion algorithm is depicted below.
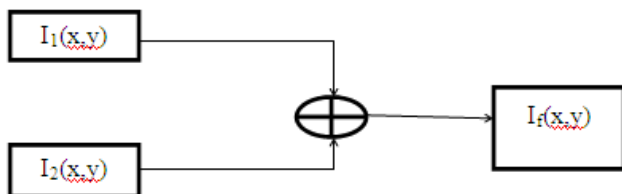
Figure-1. Information flow diagram of Pixel based image fusion.

Pixel level averaging

Averaging Method is the simplest Image Fusion technique where the weighted average of the input images is calculated, and reflects the results directly on the fused output image.

The Information flow diagram of pixel level averaging image fusion algorithm is as follows.

Figure-2. Information flow diagram of pixel level averaging.

In terms of mathematical expression for pixel averaging method is as follows:

Assuming C_0 and C_1 to be the weights the fused output Image (I_f) for the input images I_1 and I_2 is given by

$$I_f = ((C_0 * I_1) + (C_1 * I_2)) / (C_0 + C_1)$$

Averaging select maximum/minimum method

Select Maximum/Minimum method is a non-linear operation since it uses a maximum or minimum operator. Unlike averaging method wherethe average value is calculated for every corresponding pixel, a

selection process is performed in select maximum/minimum method. The pixel with maximum intensity is selected from every corresponding pixel of the input images and is used as the resultant pixel. So every pixel in the fused image will contain pixels with maximum intensity. Similarly, in select minimum method, the pixel with minimum intensity is picked up and for every pixel position the pixel of the fused image will be the pixel of the corresponding position from the input set of images having the least pixelintensity value.
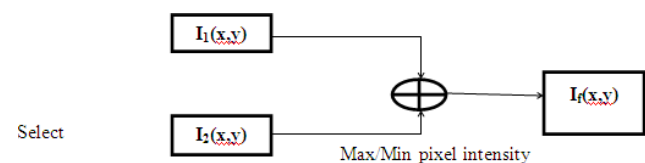
The mathematical expression for select maximum/minimum method is as follows:
The fused output Image (I_f) for the input images I_1 and I_2 is given by

$$I_f(x,y) = \max(I_1(x,y), I_2(x,y))$$

Or

$$I_f(x,y) = \min(I_1(x,y), I_2(x,y))$$

Figure-3. Information flow diagram of select maximum/minimum method.

Principal Component Analysis (PCA)

Principal Component Analysis was invented in 1901 by Karl Pearson and it was later independently developed and named by Harold Hotelling in the 1930s. Principal component analysis is a vector space transform which transforms a number of correlated variables into a number of uncorrelated variables. These uncorrelated variables are called principal components [4]. Principal component analysis is extensively used in image compression and image classification. The objective of principal component analysis is to reduce the number of variables of the dataset while retaining most of the original variability in the data. The first principal component is considered to be along the direction with maximum variance. The primary principal component accounts for as much of the variance in the data as possible and each succeeding components accounts for as much of the remaining variability as possible [4]. Principal component analysis is also called the Karhunen-Loeve transform or Hotelling transform. Principal component analysis does not have a fixed set of basis vector like FFT, DCT and wavelet transforms etc. and so its basis vector depends on the dataset.
Information flow diagram of PCA based image fusion algorithm

Let us consider, $I_1(x,y)$ and $I_2(x, y)$ to be the two given input images that are to be fused

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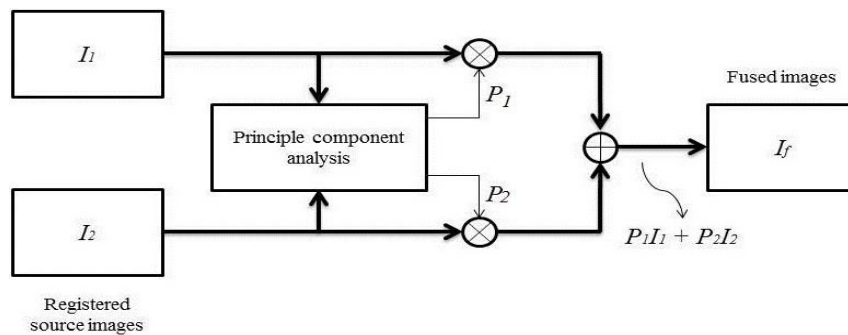
Figure-4. Information flow diagram of PCA.

PCA Algorithm

a) Calculate column vectors from input images
b) Compute covariance matrix from two column vectors
c) Calculate Eigen values and Eigen vectors from covariance matrix.
d) Normalize the column vector
e) Multiply each pixel of the input image with the normalized Eigen vector.
f) The fused image matrix will be the sum of two scaled matrices.

Intensity Hue Saturation

Intensity Hue Saturation is a colour fusion technique, which effectively separates spatial (intensity) and spectral (hue and saturation) information from an image [5]. In this fusion method the RGB image is first converted into intensity (I) hue (H) and saturation (S) components. In the next step, the intensity is substituted with the high spatial resolution panchromatic image. The last step performs the bands. In this method three multispectral bands R, G and B of low resolution. Finally, an inverse transformation from IHS space back to the original RGB space yields the fused RGB image, with spatial details of the high resolution image incorporated into it. The intensity I defines the total color brightness

and exhibits as the dominant component. After resolution using the high resolution data, the merge result is converted back into the RGB After applying IHS [7].

TRANSFORM DOMAIN IMAGE FUSION TECHNIQUES

Wavelet based image fusion

The concept of wavelet was introduced by a French physicist Morlet and theory physicist Grossman. Wavelet theory is an extension of Fourier theory. In Fourier transforms the signals are decomposed into sines and cosines whereas in wavelet transforms the signals are projected on a set of wavelet functions [2]. Fourier transforms provide high resolution in the frequency domain and wavelet transforms produce good resolution in both, frequency and time domains. Wavelet transforms are used in various fields such as image fusion, texture analysis, feature detection, data compression etc. Wavelet transforms decompose an image into different frequency bands and process those frequency bands separately. The decomposition level is usually determined according to the requirement. In this method the original image is divided into four ¼ sized sub images and these sub images are further divided into low frequency components with the same decomposition.
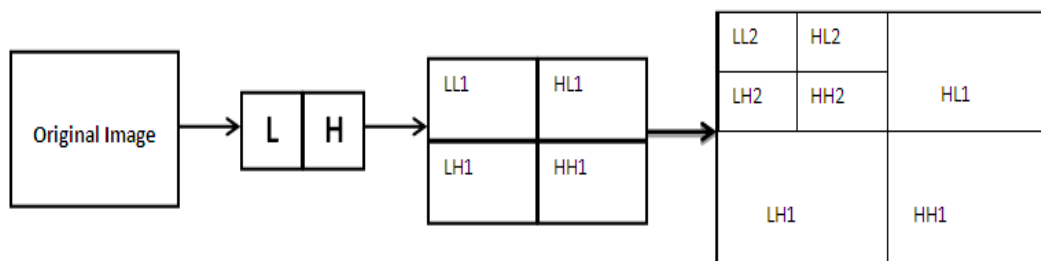
Figure-5. Frequency distribution in wavelet based image fusion.

The original image is divided into three high frequency bands (LH, HL,HH) and one low frequency band (LL) after the decomposition. Further decomposition is done only on the LL portion of the image. For example if decomposition is done N times then there will be 3N high frequency bands and one low frequency band. The reverse process of decomposition is image reconstruction which is done by increasing the sampling frequency.

Discrete Wavelet Transform (DWT)

Discrete wavelet transform converts an image from the spatial domain to the frequency domain. A wavelet is a small wave that grows and decays essentially in a limited time period. In order for a wavelet to be small, it has to satisfy two basic properties namely [2].

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a)   Time integral must be zero

$$\int_{-\infty}^{\infty} \psi(t)dt = 0$$

b)   Square of the wavelet integrated over time is unity

$$\int_{-\infty}^{\infty} \psi2(t)dt = 1$$

Wavelets are obtained from a single prototype wavelet Ψ(t) called mother wavelet by dilations and by shifting

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}} \psi\left(\frac{x-b}{a}\right)$$

In discrete wavelet transform, 'a' is the scaling parameter and is given by, $a=2^m$ and 'b' is the shifting parameter, given by $b= n2^m$.
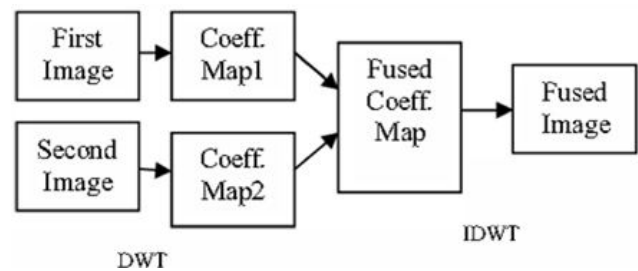Where, 'm' and 'n' are integers.

Figure-6. Image fusion using DWT.

Wavelet transform is a multi-resolution approach and is well suited for images with different image resolutions. Wavelet transform is performed on the source images and a fusion decision map is generated. The fused wavelet coefficient map can be constructed from the wavelet coefficients of the source images according to the fusion decision map. Finally the fused image is obtained by performing the inverse wavelet transform.

Stationary Wavelet Transform (SWT)
Stationary wavelet transform is translation-invariant whereas discrete wavelet transform is not a time invariant transform. In Stationary wavelet transform the process of down sampling is supressed and hence this transform is considered to be translation-invariant unlike discrete wavelet transform. Transform is applied at every point of the image and the coefficients are saved; only low frequency information is used at each level of the transform.
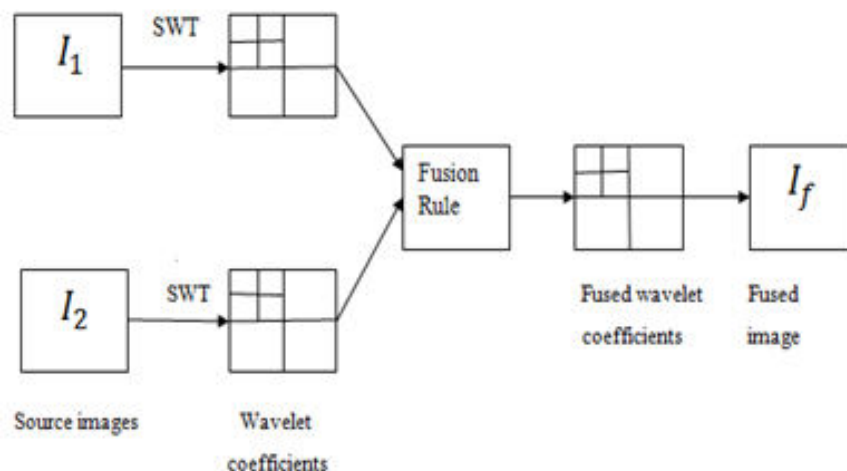

Figure-7. Information flow diagram in image fusion scheme employing SWT.

A COMPARATIVE STUDY OF VARIOUS IMAGE FUSION TECHNIQUES
A few comparisons between some of the existing image fusion techniques have been concluded and analysed theoretically based on this study and shown in the table below.

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Table-1.

S. No.	Image fusion algorithm	Domain	Advantages	Dis-advantages
1	Simple Average [5]	Spatial	Simple average image fusion algorithm is considered to be the simplest image fusion algorithm.	Pixel level image fusion algorithm does not always produce a clear output image from the given set of source images.
2	Simple Maximum/Minimum [5]	Spatial	Resulting in a highly focused image output obtained from the input image as compared to simple average. [5]	Image output obtained from pixel level image fusion technique has a blurring effect which in turn affects the image contrast.
3	Principal component analysis (PCA)	Spatial	PCA transformsa number of correlated variables into a number of uncorrelated variables which are used in image fusion [5].	This type of fusion produces spectral degradation.
4	Discrete Wavelet Transform (DWT)	Transform	DWT fusion method outperforms the basic image fusion methods, reduces spectral distortion and has a better signal to noise ratio.	Final fused output image has less spatial resolution.
5	Combine DWT, PCA	Transform	Multi-level fusion technique where the image fusion is done twice using efficient fusion algorithm.Output image has high spatial and spectral resolution.	The transformation is complex in nature and requires better fusion techniques for good results.

CONCLUSIONS

This paper performs a survey on various image fusion techniques in spatial and transform domain. A comparison of some of the spatial and transform domain image fusion techniques using simple average, simple maximum/ minimum image fusion, principle component analysis, wavelet transform. Depending upon the type of the application and the requirement of the user different fusion algorithm can be chosen. One might have the desire to obtain visually beautiful image someone else may requiremore details on the colours of that particular image for getting more detailed accurate results about the image. Spatial domain image fusion technique provides high spatial resolution but the images usually have blurring effects.

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