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A Review on Various Image Fusion Techniques

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Abstract: Image fusion is a process to merge the information from two or more images to obtain a resultant image of higher quality and information. There are numerous techniques available to fuse the images. These techniques are categorized into spatial domain, transform domain and statistical based methods. This paper contains the review of some of the techniques under each type and draws a conclusion from their performance analysis.

Keywords: Image Fusion, Types of image fusion, Entropy (En), Peak Signal to Noise Ratio (PSNR)

I.INTRODUCTION

The term 'fusion' means joining of two or more entities together to form a whole. Image fusion (IF) means combining two images into a single image that has maximum information content.[1] As a technique IF means to integrate the features of the same scene taken by different sensors (multimodal), at different time (multitemporal) or taken from different views (multiview) to form a single image of much higher quality than its constituent scenes. The property of synergism is exploited in IF. By fusing multiple information sources a more detailed fused image is formed. Fused image is used in image processing tasks like object recognition, segmentation, image analysis, feature extraction, human visual system etc [2]. Use of older techniques such as averaging, minimum/maximum select etc. does not recover good fused image in terms of performance parameters like peak signal to noise ratio(PSNR),Normalized correlation(NC), and mean square error(MSE) where as recent techniques such as wavelet packet transform, Fractional Fourier transform, hybrid methods etc, have resulted in better fused image. The rest of the paper is as follows: Section II represents the type of IF technique, Section III gives Performance Metrics of the techniques, Section IV presents the performance analysis and lastly Section V deals with the Conclusion of the paper.

II. IMAGE FUSION TECHNIQUES

Any image fusion technique falls under three categories of levels [2]. These are:

a) Pixel Level or low level IF,
b) Feature level or Middle level Image fusion,
c) Decision or high level image fusion

IF at pixel level is the lowest processing level which generates a fused image in which each pixel is determined from set of pixel in each source images. The medium level IF employs feature extraction on source data so that features from each source can be employed. These features include edge shape, image profile angle texture, similar depth of focus area etc. In highest level IF or decision level IF all decision and control are decided according to result of decision of sensor information. IF techniques belong to either of following two domains [1]:

- Spatial Domain
- Transform domain

Spatial domain deals directly with the image pixels which are manipulated to achieve desired result. Transform or frequency domain transforms the image using the mathematical equation in frequency domain.

Another category is Statistical based IF which uses statistical approach to eliminate the problem of data dependency[3].Image fusion has been an area of extensive research since past few years and many techniques have been evolved to suit the different purposes. Some of them are given as:

A. Techniques under Spatial Domain:

a) Principle Component Analysis
b) Averaging Method
c) Maximum/Minimum select Method
d) IHS Transform Technique

B. Pixel Based Statistical and Numerical Techniques

a) The LMM and LMVM Technique
b) Regression Variable Substitution

C. Techniques under Frequency Domain:

a) Laplacian Pyramid based Decomposition Technique
b) Discrete wavelet Transform technique
c) Fractional Fourier Transform technique

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A. SPATIAL DOMAIN TECHNIQUES:

A. a) Principal Component Analysis (PCA) based Fusion

PCA is a mathematical tool which transforms a number of correlated variables into a number of uncorrelated variables called principal components [4]. The PCA is used extensively in image compression and image classification. It computes a compact and optimal description of the data set. The process of PCA fusion is shown in Fig.1.

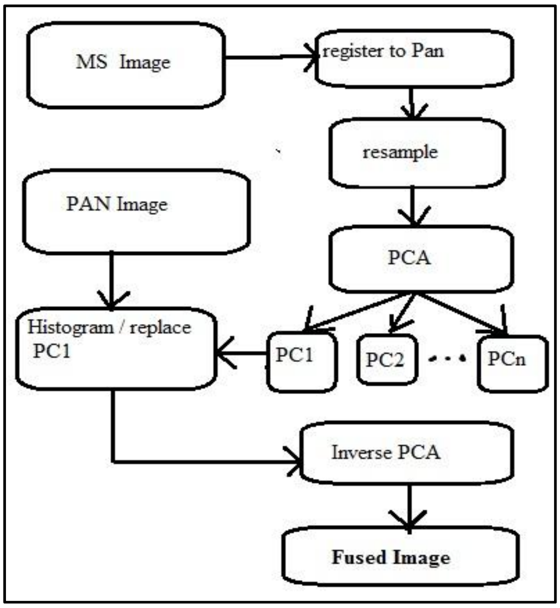

Fig.1 PCA Image Fusion

The main advantage of PCA is that we can have a large number of inputs and that most of the information within the inputs can be compressed into a much smaller amount of outputs without much loss of information.

A. b) Averaging Method

The simplest way of image fusion is to take the average of the two images pixel by pixel. Averaging technique works well when the images to be fused are from the same type of sensor and contain additive noise.

However, this method usually leads to unwanted side effect such as reduced contrast[5].More robust algorithm for pixel level fusion is the weighted average approach. The weight estimation usually requires a user-specific threshold. Thus the given algorithm is a simple way of obtaining an output image with all regions in focus.

$$I(x, y) = \frac{I1\,(x,y) + I2\,(x,y)}{2} \qquad (1)$$

Where I1 (x, y) & I2 (x, y) are the input images and I(x, y) is the fused image.

A. c) Maximum/Minimum Select Method

The greater the pixel values the more in focus the image. Thus maximum select method chooses the in-focus regions from each input image by choosing the greatest value for each pixel, resulting in highly focused output.

The value of the pixel P (i, j) of each image is taken and compared to each other. The greatest pixel value is assigned to the corresponding pixel[6].

$$F(i,j) = \sum_{i=1}^{M} \sum_{j=2}^{N} maxA(i,j)B(i,j) \qquad (2)$$

A and B are input images and F is fused image.

In minimum select method fused image is obtained by selecting the minimum intensity of corresponding pixels from both input image A and B. If F is the fused image then by this method [6],

$$F(i,j) = \sum_{i=1}^{M} \sum_{j=2}^{N} minA(i,j)B(i,j) \qquad (3)$$

A. d) Intensity–Hue– Saturation (IHS) Fusion Technique

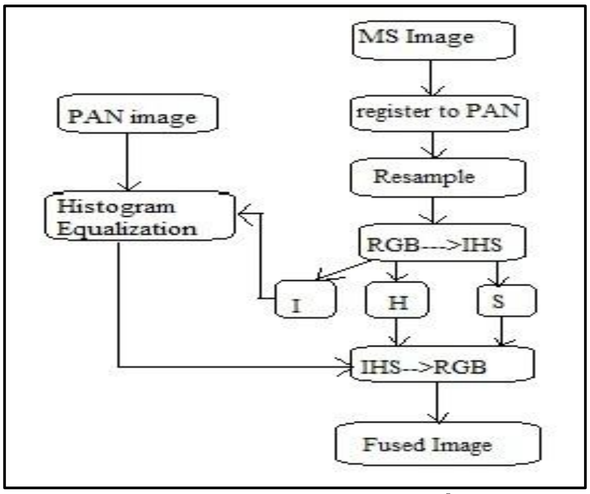

Fig.2. Intensity Hue Saturation Technique

IHS is a common way of fusing high spatial resolution, single band, pan image and low spatial resolution, multispectral remote sensing image. The R, G and B bands of the multi spectral image are transformed into IHS components, replacing the intensity component by the pan image, and performing the inverse transformation to obtain a high spatial resolution multispectral image[4].

The flow diagram of HIS technique is shown in Fig.2.IHS can enhance spatial details of the multispectral image and improve the textural characteristics of the fused image. Although the IHS method has been widely used, the method cannot decompose an image into different frequencies in frequency space such as higher or lower frequency apart from this spectral distortion may occur with the fused image.

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B.STATISTICAL TECHNIQUES:

Statistical methods are employed for fusing the multispectral and panchromatic images. These methods solve color distortion and data dependency problem in fused image. [7]The statistical methods are given as follows:

B. a) Local Mean Matching and Local Mean Variance Matching

Both the technique integrates panchromatic images into multispectral images that are resampled to the same size.
The LMM algorithm is given by:

$$Fk(i,j) = P(i,j) \times \frac{\bar{M}k(i,j)(w,h)}{P(i,j)(w,h)} \qquad (4)$$

Here Fk(i,j) is the fused image,P(i,j) is high spatial resolution image and Mk(i,j) is the low spatial image resolution.(i,k) represent the pixel coordination.
The LMVM algorithm is given by equation:

$$Fk(i,k) = \frac{(P(i,j) - \bar{P}(i,j))\, \sigma\, Mk(i,j)(w,h)}{\sigma P(i,j)(w,h)} + \bar{M}k(i,j) \qquad (5)$$

Here σ is the local standard deviation. (w,h) is the window size of 11 x 11 pixels. This window size can varied according to our use. Small size windows produces less distortion whereas larger filtering windows incorporate more structural information from high resolution image at the cost of distortion of spectral values.

B. b) Regression Variable Substitution:

In image fusion the regression variable can be used to determine a replacement vector of an image that can be replaced by another image channel. This substitution of linear combination (replacement vector) of image channel is called Regression Variable Substitution. The process of IF through this method is shown by Fig. 3. Scaling parameter and bias parameter are calculated by least square between MS and PAN image resampled band.

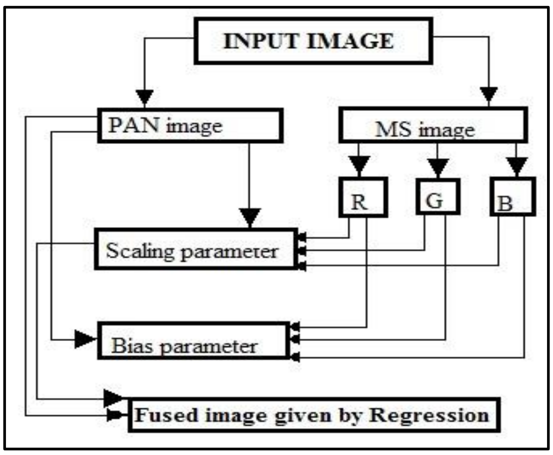

Fig.3. RVS Method

The scaling parameter is given by b_k,

$$b_k = \frac{SpMk}{Spp} \qquad (6)$$

Where SpMk is covariance between P and Mk of band k and Spp is the variance P. The bias parameter is given by a_k,

$$a_k = \bar{M}k - b_k . \bar{p} \qquad (7)$$

Here $\bar{M}k$ is mean of Mk and $\bar{p}$ is mean of P. Finally the Regression variable is given by,

$$F_k = a_k + b_k . p \qquad (8)$$

C.TRANSFORM DOMAIN TECHNIQUES:

In transform domain methods the image is first transformed into frequency domain by various transforms such as wavelet transform, Laplacian pyramid, DWT, DCT, FRFT etc. All fusion operations are done in transformed image (frequency domain) then the resultant image is found using inverse transform. This method encompasses a lot of techniques; some of them are given below:

C. a) Laplacian Pyramid Decomposition Method:

Laplacian pyramid (LP) represents the edge of image detail at every level. If Laplace level pyramid of two images of same scene is taken and then integrated, a fused image is obtained with much higher information than the source images. [8] The image fusion using this method is shown in figure 4 .Firstly LP decomposition is done on the registered image of A and B separately.
The differential layers of A and B obtained by the LP transform are mixed with each other. This occurs by fusing the differential fused image separately.

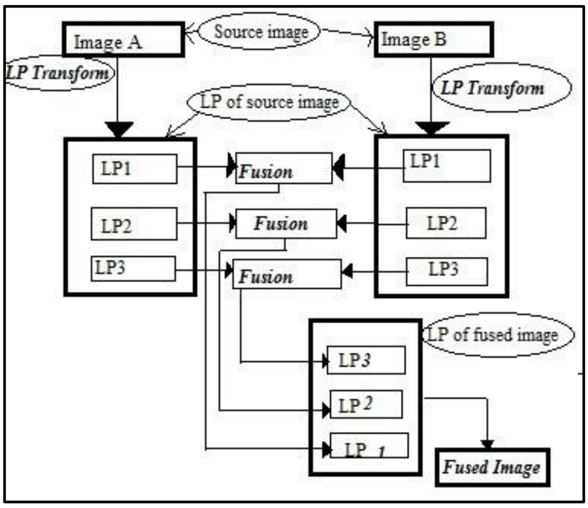

Fig.4. LP Decomposition Method

The resultant differential layers are obtained which are followed by inverse Laplace transform to obtain a fused image.

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C. b) Discrete Wavelet Transform Method(DWT):

The Wavelet based image fusion is given as :

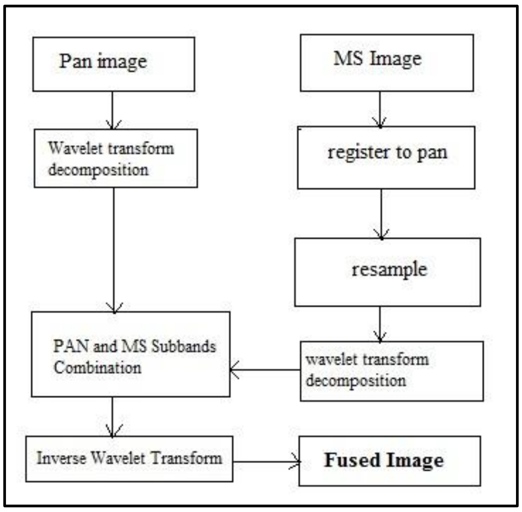

Fig.5 Wavelet Image Fusion

The panchromatic images is decomposed directly using discrete wavelet transform and multispectral image goes through registration and resample process then decomposition occurs[4]. The coefficients obtained after transformation are combined to obtained detailed coefficients. Finally the fused image is obtained after taking inverse discrete transform.

C. c) Fractional Fourier Transform Based Method (FRFT):

Image signal from time domain x(t) is transformed into frequency domain $x_p(u)$ using FRFT. Since the order of FRFT changes continuously it can be adjusted to meet requirements in image processing [9]. Fractional differential operates on image enhances image signal high frequency and retains very low frequency components i.e. texture details of image smoothing region so as to preserve the image texture information.

FRFT is defined as :

$$x_p(u) = F_p[x](u) = \int_{-\infty}^{+\infty} x(t)K_p(t,u)dt \quad (9)$$

Where, p is the order of FRFT. $\alpha = \frac{p\pi}{2}$ is the FRFT operator and $K_p(t,u)$ is the transform kernel:

$$K_p(t,u) = \begin{cases} (\sqrt{1-jcot\alpha})expj\pi(t^2cot\alpha \\ -2ut\,cosec\alpha + u^2cot\alpha), \alpha \neq n\pi \\ \delta(t-u), \quad \alpha = 2n\pi \\ \delta(t+u), \quad \alpha = (2n \pm 1)\pi \end{cases} \quad (10)$$

The inverse transform for FRFT:

$$x(t)F_{-p}[x_{-p}](t) = \int_{-\infty}^{+\infty} X_p(u)K_{-p}(t,u)du \quad (11)$$

After the decomposition of image spectrum similarity (S) is used to avoid distortion at the edge where grey values change. If T is a threshold and S≤T indicated two regions difference is large then larger spectrum coefficient is selected directly as fusion coefficient then,

$$\begin{cases} f_F(i,j) = f_A(i,j) \ \ if \ \ f_A(i,j) \geq f_B(i,j) \\ f_F(i,j) = f_B(i,j) \ \ if \ \ f_A(i,j) \leq f_B(i,j) \end{cases} \quad (12)$$

Else if S > T indicates two region have high similarity then weighted fusion method is used to smooth the final image. Weighted coefficients are given by:

$$W_{min} = 0.5 - \frac{0.5(1-S)}{1-T} \quad (13)$$

$$W_{max} = 1 - W_{min} \quad (14)$$

Fused image in this case will be,

$$\begin{cases} f_F(i,j) = W_{max}\, f_A(i,j) + W_{min}\, f_B(i,j) \\ \quad if\ f_A(i,j) \geq f_B(i,j) \\ f_F(i,j) = W_{max}\, f_B(i,j) + W_{min}\, f_A(i,j) \\ \quad if\ f_B(i,j) \geq f_A(i,j) \end{cases} \quad (15)$$

Where, $f_F(i,j)$ represents fused image with $f_A(i,j)$ and $f_B(i,j)$ as its coefficients.

II. PERFORMANCE MEASURES

An image fusing method should be able to derive all the valid and useful information from the source image without introducing any noise.

The performance of the fused image can be done visually but for the detailed analysis statistical methods are used. There are many methods are available, but for this paper following methods are given.

2.1) Entropy: It is an index to evaluate the information quality in the image. It is also known as average information content per source symbol. As entropy increases after the fusion of an image then the information also increases.

$$E = -\sum_{i=0}^{L-1} p_i \log_2 p_i \quad (16)$$

Here L is total of grey levels and probability distribution of each level is given by p = $\{p_0, p_1, p_2, \ldots p_{L-1}\}$

2.2) Peak Signal to Noise Ration (PSNR): It is the ratio between the maximum possible power of signal and power of corrupting noises that effects the fidelity of its representation.

$$PSNR(dB) = 20\log\frac{255\sqrt{3MN}}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(B'(i,j)-B(i,j))^2}} \quad (17)$$

B-perfect image, B'-fused image, i-pixel row index, j-pixel column index , M and N- no. of rows and column.

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2.4) Normalized Cross Correlation (NCC): It is used to find the similarities between fused image and registered image. It is given by equation:

$$NCC = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij} * B_{ij})}{\sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij})^2} \quad (18)$$

2.5) Information Entropy: This is metric is used in the FRFT method. Information entropy is given as:

$$E^p = -\sum_{i=1}^{M}\sum_{j=1}^{N} P_{i,j}\log P_{i,j} \quad (19)$$

Here M × N is the image size.

III. PERFORMANCE ANALYSIS

The data from given table is taken from various sources to understand the performance of each techniques in terms of their entropy. The data in techniques from LMM to RVS are derived from the graphical source hence their approximate values are given[7].

Considering the following data it is seen that the entropy is comparatively high in minimum and maximum select techniques in the spatial method. For Statistical methods RVS has highest entropy than LMM and LVMM. On comparing FRFT, DWT and LP methods it is found that discrete wavelet transform method has high entropy and it yields better image than FRFT and LP.

TABLE 1.COMPARISON OF ENTROPY OF TECHNIQUES

Sno	Techniques	Entropy
1	PCA[6]	7.49
2	Averaging[11]	7.22
3	Max. Select[6]	9.14
4	Min. Select[6]	9.14
5	HIS[10]	5.89
6	LMM[7]	5.91
7	LMVM[7]	5.72
8	RVS[7]	5.92
9	LP[8]	7.41
10	DWT[12][13][14]	7.42
11	FRFT[9]	5.04

But the performance of an IF technique cannot be judged on the basis of entropy alone. An IF technique must have a low run time, should not introduce any distortion, and must not be too complex. On average spatial techniques have low run time but their fused images have colour distortion and blurs. Statistical methods reduces colour distortion and automates the fusion process[3]. The transform methods take more run time and are more complex than former methods.

IV. CONCLUSION

It has been observed that the techniques mentioned in the paper perform fusion satisfactorily but have some issues or the other. The spatial domain techniques are less complex than transform domain and statistical methods. In this domain averaging, minimum select and maximum select are simplest methods but the colour resultant images get colour distorted and blurry. PCA and HIS methods have fast processing time lower complexity as well as colour distortion is reduced to some extent. Statistical method reduces colour distortion .Out of all the statistical techniques RVS yields the image with high information and resolution .This method is used in multispectral remote sensing[7].

Laplace pyramid method gives good result visually and quantitatively but needs improvement in terms of complexity and real time operation. FRFT method gives high contrast image with clear visual effects. The practical application of FRFT method includes fusing infra red images[9].DWT techniques have an advantage over pyramid techniques due to increased directional information and better SNR[5].

From the study it is seen that an IF algorithm must have low run time, should be automated, must not introduce distortion and should extend the adaptability of previous fusion methods. Finally this paper concludes that PCA method, RVS method and DWT method yield image with high information content and comparatively low distortion as compared to the other mentioned techniques.

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