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Digital Image Fusion Techniques: A Review

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ABSTRACT

Image Fusion is a technique of obtaining images with high spatial and spectral resolution from low spatial resolution multispectral and high spatial resolution panchromatic images. There is often an inverse relationship between the spectral and spatial resolution of the image. It has not been possible to propose a single sensor package that will meet all our application requirements, while the combined image from multiple sensors will provide more comprehensive information by collecting a wide diversity of sensed wavelengths and spatial resolutions. Due to the demand for higher classification accuracy and the need in enhanced positioning precision there is always a need to improve the spectral and spatial resolution of remotely sensed imagery. These requirements can be fulfilled by the utilization of image processing techniques at a significantly lower expense. The goal is to combine image data to form a new image that contains more interpretable information than can be gained by using the original information. Ideally the fused data should not distort the spectral characteristics of multispectral data as well as it should retain the basic colour content of the original data. If the fused images are used for classification, then the commonly used merging methods are Principal Component Analysis(PCA), Intensity hue saturation method (IHS), Brovey transformation, multiplicative technique (MT), High-pass Filter (HPF), Smoothing Filter-based Intensity Modulation(SFIM) and Wavelet Transform.

Keywords: Image Fusion, PCA, IHS, BT, MT, HPF, SFIM and Wavelet Transform

I. INTRODUCTION

Image fusion is a process of combining two or more images, obtained from new and composite Images using a certain algorithm .image fusion are to integrate different data in order to obtain more information than that can be derived from each of the single sensor data alone, image fusion has been applied to achieve a number of objective like image sharpening, improving geometric correction, complete data set for improved classification, change detection, substitute missing information, replace defective data.

Data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different source gives "different quality " means that will depend[2] upon the application. Image fusion is mainly used in to enhance the visual interpretation, and it is not only used in improving the image classification the main reason is as follows:

- Image fusion is mostly based on the fusion of different satellite. Because of the difference of the various parameters and phase between different sensors, as well as the inevitably registration error, led to the fusion classification results unsatisfactory.
- Although the same sensor system provided different spatial resolution images, because of its low spatial resolution, resulting in poor classification effect.
- Because of the unreasonable fusion algorithm or classification method make the failure of classification

Image fusion takes place at three different levels: pixel, feature, and decision [1]. In pixel-level fusion, a new image is formed whose pixel values are obtained by combining the pixel values of different images through some algorithms. The new image is then used for further processing like feature extraction and classification. In feature-level fusion, the features are extracted from different types of images of the same geographic area. The extracted features are then classified using statistical or other types of classifiers. In decision-level fusion, the images are processed separately. The processed information is then refined by combining the information obtained from different sources and the differences in information are resolved based on certain decision rules. Figure 1 provides a visual interpretation of the different levels of fusion.

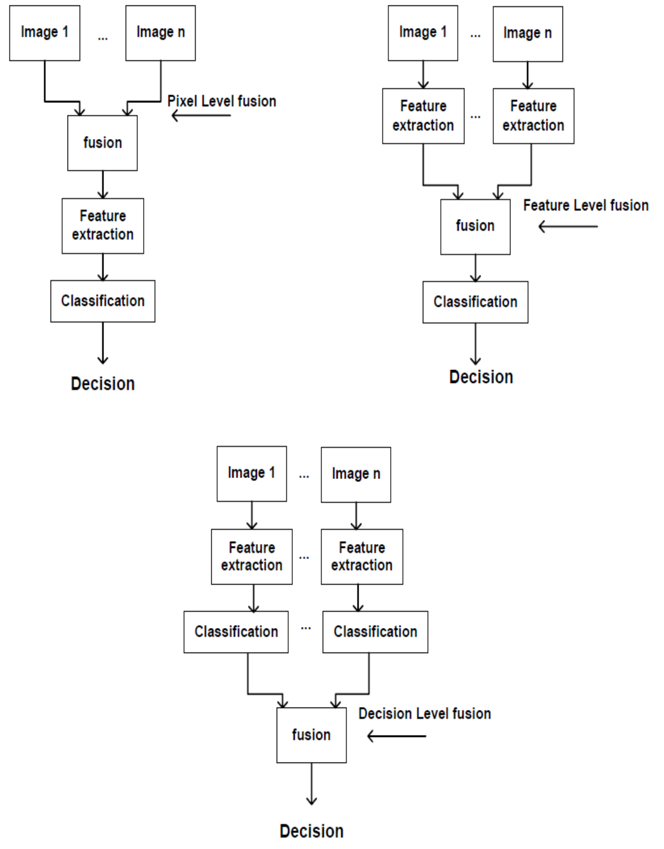

Figure 1: Levels of Image Fusion

II. FUSION PRINCIPLE

The fused images as a linear combination of the pan and XS images. To create a new fused pixel, corresponding pixels in the pan and XS images are multiplied by the weighting factors “a” and “b” respectively. The sum of the new weighted pixels from the pan and XS images will form the new fused pixel. This can be expressed by the following expression:

$$F_{k\,(m,\,n)} = n_{(m,\,n)} * I_{0\,(m,\,n)} + b_{(m,\,n)}\, I\, k_{(m,\,n)} \quad \ldots \quad (1)$$

Where, m and n are the rows where m and n are the row and column numbers, k = 1, 2, …., N (N = number of XS bands); F_k is the fused image, I_o is pan image and I_k is the XS band. The above relationship is only valid for a certain window, i.e., the *a* and *b* Coefficients must be determined window by window. For the easy notation, the 1-D subscript *i* for window locations and the band number *k* is ignored. For the simplicity, 3x3 and 5x5 windows are used in the figure. To calculate $a_{(6,\,6)}$ and $b_{(6,\,6)}$ 3x3 window is selected such that Pan (6, 6) and XS (6, 6) pixels are the centre pixels of the 3x3 window. Once a (6, 6) and b (6, 6) coefficients are determined using the two criteria introduced above, the fused pixel F (6, 6) is calculated via Equation 1.

If user wants the fused image with the same size of the input images, then padding process will be needed for the border regions of the input images. The blue pixels surrounding the input images represent the padding area. To calculate F (12, 12) with a 5x5 window, pan and XS images are enlarged such that all the pixels within the window have a pixel value. There are various padding approaches in the literature (e.g., zero padding approach which extends the images with zeros). In this study no padding was used. Therefore, the fused images are smaller in size than the input images depending on the window sizes used.

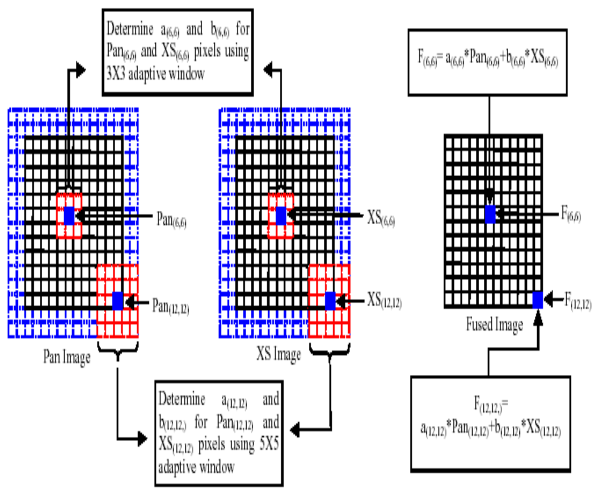

Figure 2: Construction of fused pixels using a pan and xs image

III. BACKGROUND FOR DATA SOURCE

A. Spatial resolution

Spatial resolution of an imaging system is expressed as the area of the ground represented by one pixel. The instantaneous field of view (IFOV) is the ground area sensed by the sensor at a given instant in time. The spatial resolution is dependent on the IFOV. The finer the IFOV is, the higher the spatial resolution. Spatial resolution is also viewed as the clarity of the high frequency detail information available in an image. As the spatial resolution increases the details in an image are clear.

As one can see from the images, the detail information in the images becomes clear as the spatial resolution increases from 11.2 m to 2.8 m. Spatial resolution is usually expressed in meters or foot in remote sensing. In medical imaging, it is expressed in millimetres.

B. Spectral resolution

The spectral responses measured by remote sensors over various features often permits an assessment of the type and condition of the features, these responses have often been referred to as “spectral signature”. Spectral resolution is the width within the electromagnetic spectrum that can be sensed by a band in a sensor. The narrower the spectral bandwidth is, the higher the spectral resolution. If the platform has a few spectral bands, typically 4 to 7, they are called multispectral, and if the number of spectral bands in hundreds, they are called hyper spectral data

TABLE 1: THE DIFFERENT RANGES OF WAVELENGTH IN THE EMR

Spectrum	Wavelength
Gamma rays	< 0.03 µm
X rays	0.03-0.3 µm
Ultraviolet rays	0.3-0.4 µm
Visible region	0.4-0.7 µm
Infrared region	0.7-1.0 µm
Reflected infrared band	0.7-3.0 µm
Thermal infrared band	3.0-5.0 µm
Radar	0.1 to 30 cm
Radio waves	>30 cm

IV. IMAGE FUSION METHODS

Image fusion methods are all based on pixel-level fusion method is a process to analysis the original information, this fusion method loss the least information so the accuracy of the pixel level fusion is the highest, but the data transmission and processing is the largest.

A. Transformation Based Fusion

1) Principal Component Analysis Method:

The principal component analysis (PCA) is widely used in signal processing, statistics, and many other applications [4]. The PCA involves a mathematical procedure that transforms a number of correlated variables into a set of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. There can be as many possible principal components as there are variables. It can be viewed as a rotation of the existing axes to new positions in the space defined by the original variables. In this new rotation, there will be no correlation between the new variables defined by the rotation. The PCA is widely used for dimensionality reduction and data analysis. The PCA is computed using the Eigen values and eigenvectors of the covariance matrix of the multispectral image bands. The Eigen values indicate the variance along the principal components and the eigenvectors denote the direction of the principal components. The Eigen values are arranged in decreasing order of magnitude. The transformation matrix for computing principal components is obtained by arranging the eigenvectors in the order corresponding to that of the Eigen values. Thus the first principal component corresponds to the direction of the highest Eigen values or maximum variance. The second principal component corresponds to the second maximum variance and so on.

2) Intensity-Hue-Saturation Method:

The Intensity-Hue-Saturation (IHS) transformation decouples the intensity information from the color carrying information [5]. The hue attribute describes a pure color and saturation gives the degree to which pure color is diluted by white light. This transformation permits the separation of spatial information into one single intensity band. There are different models of IHS transformation. The models differ in the method used to compute the intensity value. Hexacone and triangular models are two of the more widely used models [3]. The hue and saturation values are computed based on a set of complex equations. The intensity value for the hexacone model and triangular model is computed as shown in equations

$$I = \max(r, g, b) \quad \text{.............(2)}$$

$$I = \frac{R+G+B}{3} \quad \text{.............(3)}$$

$$I = \frac{\max(R,G,B)+\min(R,G,B)}{2} \quad \text{............(4)}$$

This model ignores one of the three components to compute the intensity. The changes in the intensity values are not distributed evenly in all the three R, G, and B components when the inverse transform is performed. All the three models have different set of equations to compute the hue and saturation values.

3) Standardised Principal Component (SPC) Transformation:

This method uses the correlation matrix to determine the transformation matrix instead of the covariance matrix. The main advantage in comparison to the principal component transformation is that all bands are considered equally important [2]. This is of particular interest for the imagery under investigation as the near infrared band exhibits a superior variance and thus would dominate the fusion process.

B. Additive and Multiplicative Technique

1) Brovey Transform:

Ratio images are very useful in change detection. The Brovey transform, named after its author. The Brovey transform is a formula based process that is based on the band to display in a given colour, the sum of all the colour layers, and the intensity layer. The Brovey transform uses a formula that normalizes multispectral bands used for an RGB display, and multiplies the result by any other higher resolution image to add the intensity or brightness component to the image. The formula is as follows:

$$\begin{aligned} R &= (R/(R+G+B)) * I \\ G &= (G/(R+G+B)) * I \\ B &= (B/(R+G+B)) * I \end{aligned} \qquad \ldots\ldots \quad (5)$$

Where R = Red, G = Green, B = Blue, I = Intensity

The Brovey Transform can also be expressed as;

$$DN_{\text{fussed MSI}} = \frac{DN_b}{DNb_1 + DNb_2 + \ldots\ldots\ldots + DNb_n} \, DNpan \quad \ldots\ldots \quad (6)$$

The Brovey transform provides excellent contrast in the image domain but affects the spectral characteristics a great deal [7].

2) Multiplicative *Technique (MT):*

The multiplicative technique (MT) is grouped under the arithmetic method which uses the four possible arithmetic methods (addition, subtraction, division and multiplication) to incorporate an intensity image into an achromatic image. The MT algorithm is based on the following relation

$$\begin{aligned} DN\,R\,(new) &= DNR * DN\,PAN \\ DN\,g\,(new) &= DN\,g * DN\,PAN \\ DN\,B\,(new) &= DN\,B * DN\,PAN \end{aligned} \qquad \ldots.. \quad (7)$$

DN*R*, DN*G* and DN*B* = Digital number of the corresponding pixel belonging to the R, G and B bands

DN PAN = Digital number of the corresponding pixel belonging to the panchromatic band

DN new = New digital number of the corresponding pixel of the respective band

3) Colour normalised (CN) transformation:

The colour normalised transformation [6] fuses the two spectral and spatial data sets assuming there is a certain spectral overlap between the multispectral bands and the more highly resolved panchromatic band. This constraint is violated for the near infrared band XS3 and results in poor fusion results. Equation (5) shows the merging process whereby the additive constants avoid division by zero.

$$XS_i^R = \frac{3(XS_i^R + 1)(P_N + 1)}{\sum_I XS_i^R + 3} - 1 \qquad \ldots\ldots. \quad (8)$$

C. Wavelet Method

The wavelet transform is a mathematical tool extensively used in image analysis and image fusion. Using multi-resolution analysis, the multispectral and the panchromatic images were decomposed into an orthogonal wavelet representation at a coarser resolution, which consisted of low frequency approximation image and a set of high frequency detail images. The detail images from the high resolution panchromatic image are incorporated into the decomposed multispectral images at a level the resolution of the ground cover matches and the inverse transform is taken

The steps involved in merging images using wavelet method is as follows

- Resample the multispectral image to make its pixels size equal to that of the panchromatic images. The multispectral and panchromatic images are geometrically corrected using ground control points, so that they can be merged.
- Apply the discrete Wavelet transform to the “histogram-matched” panchromatic image and to the “resampled” multispectral image, using the Daubechies four coefficient wavelet basis. Four half-resolution images (Ca, Ch, Cv and Cd) are obtained from each multispectral and panchromatic full resolution image.
- Repeat step 2 to generate wavelets for each level till the resolution of the image matches by using the approximation image as input for each level.

- Using the detail images (Ch, Cv and Cd) from each decomposition, generate the detail images that are going to be replaced in the multispectral decomposition.

The detail images can be generated using the following formula,

$$C_h^* = (C_h^p + C_h^{m)}/2$$
$$C_V^* = (C_v^p + C_v^{m)}/2 \quad \ldots\ldots \quad (9)$$
$$C_d^* = (C_d^p + C_d^{m)}/2$$

Where, Ch *, Cv *, Cd * are the detail images generated that are going to be replaced in the multispectral decomposition Ch p, Cv p, Cd p are the detail images generated from the panchromatic data Ch m, Cv m, Cd m are the detail images generated from the multispectral data.

D. Filter Fusion Method

1) High-pass Filter Fusion Method (HPF)

High-pass filter fusion method a method that make the high frequency components of high-resolution panchromatic image superimposed on low resolution multispectral image, to obtain the enhanced spatial resolution multispectral image.

The formula is as follows**:**

$F_k(i,j)=M_k(i,j)+HPH(i,j)$ ……… (10)

In the above formula $F_k(i,j)$ is the fusion value of the band K pixel (i,j), $M_k(i,j)$ the value of multi-special of band k pixel (i,j) HPH(i.j) show the high frequency information of the high resolution image.

2) Smoothing Filter-based Intensity Modulation

Smoothing Filter-based Intensity Modulation is a brightness transformation is based on the smoothing filter. The formula of this arithmetic is as follows:

$$B_{SFIM_I} = \sum_J \sum_K \frac{B_{LOWr,k} \times B_{HIGHf,k}}{B_{MEANf,k}} \quad \ldots\ldots \quad (11)$$

In the above formula B_{sfim} is the fusion image generated by this arithmetic, I is the value of the band, J and K is the value of row and line; BLOW is the Low-resolution images, B_{MEAN} is simulate low-resolution images, which can be obtained by low-pass filter.

E. Fusion Based on Interband Relation

1) Regression fusion (RF*)*

Due to the high correlation between the visible bands, the relation between one of the fused visible wavelength range images and the high resolution band can be expressed by the simple regression shown in Equation 12. The bias parameter a_i and the scaling parameter b_i can be calculated by a least squares approach between the resampled band XS^R i and P_N.

$$XS_i^H = a + b * p_{1\ldots n} \quad \ldots\ldots\ldots \quad (12)$$

The regression technique is not suitable for the near infrared band since the global correlation is weak. However, significant improvements can be obtained using a local approach. Instead of computing the global regression parameters, the a_i and b_i parameters are determined in a sliding window.

2) Look-up-table (LUT) fusion

The regression method suffers even for local processing of the near infrared band from the use of the least squares approach. A non-linear approach like the use of lookup- tables helps to overcome this deficit. The up sampled versions of the multispectral bands are compared with the corresponding high-resolution pixels using a local pixel neighbourhood. Finally the radiance values of the bands X_{SRi} are manipulated with respect to the generated tables. Care must be exercised in choosing the size of the neighbourhood and in preventing artifacts.

V. CONCLUSION

There are no generalized criteria for the selection of a particular fusion technique. The selection of the fusion method for an application depends largely on the dataset. The image fusion methods are used to generate high resolution image that attempts to preserve the spectral characteristics of the original data. For image fusion methods, Spatial Enhancement, Spectral Preservation and Speed are all critical issues.

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