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Archives of Applied Science Research, 2011, 3 (4):206-217
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

The critical analysis of various image fusion techniques for enhanced image features interpretation in remote sensing applications

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ABSTRACT

Multi sensor data fusion technique combines data and information from multiple sensors to achieve improved accuracies and better inference about the environment than single sensor. The paper presents an objective evaluation of three image fusion techniques. The fusions techniques based on Brovey Transform, Integration of substitution (IHS), discrete wavelet transform (DWT) using additive Wavelet (WT) was performed. The fused image is evaluated in 1:50000 scale. From visual aspect, the spatial and spectral resolutions of all the images have been enhanced compared with the source MS images. The result of fusion using IHS (both cylindrical and triangular models) fusion has more spatial resolution as compared to the other fusion methods although they exhibit color distortion for vegetation cover. The DWT fusion gave the optimum spectral enhancement when the level used was three. At higher levels, the color fades gradually. The IHS with DWT causes color distortion in the fused image, whereas the additive wavelet based fusion method preserves the original spectral content.

Keywords: Remote sensing, Image fusion, High resolution, Multi-sensor, Panchromatic, Multispectral.

INTRODUCTION

The field of remote sensing is a continuously growing field with applications in different fields like vegetation mapping, urban studies and observation of the environment. The increase in applications is due to the availability of high quality images for a reasonable price and improved computation power. However, as a result of 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 either fulfilled by building new satellites with a superior resolution power, or by the utilization of image processing techniques. The main advantage of the second alternative is the significantly lower expense.

This article gives an introduction to various techniques used for the image fusion of remotely sensed imagery and illustrates examples obtained for multi-spectral imagery. The goal is to combine the image data to form a new image that contains more interpretable information than could be gained by using the original information hence can be defined as the process by which several images or some of their features can be combined together to form a single image.

The fusion of images is the process of combining two or more images into a single image retaining important features from each. Otherwise it can be defined as the process by which several images or some of their features are combined together to form a single image. Image fusion can be performed at different levels of the information representation. Four different levels can be distinguished according to signal, Pixel, feature and symbolic levels. Several approaches to image fusion can be distinguished, depending on whether the images are fused in the spatial domain or they are transformed into another domain, and their transforms fused.

In this work an image of higher spatial resolution called panchromatic image and a comparatively lower spatial resolution with considerable spectral content called as multispectral image as input images are fused to form a new image which has more interpretable information as compared to the input images using various fusion techniques, some of which have been implemented and discussed. We have discussed the pixel-based fusion which is performed at the level of spectral radiance values and offers minimum of original spectral information.

The fusion technique requires the input images to be registered with high accuracy of less than half a pixel, since mis-registration can cause artificial colors in features of data, thereby leading to falsifying of interpretation. The image fusion techniques can be categorized into three types, color-related, numerical/ statistical-related and a combination of the three approaches. All color related techniques employ slicing of original data into their respective layers, which can be basic Red (R)Green (G) Blue (B), human perceived Integration of Substitution (IHS), HSV or more scientific luminance–chrominance. This is followed by substitution by a high resolution image in place of one of these channels and a back-transformation of this combination into the original RGB domain. The application specified decides on the choice of image channel to be substituted. The statistical method, as indicated by its name, uses a mathematical approach for data integration. It involves addition, multiplication, differencing, ratioing of low and high resolution data prior to their integration. Inclusion of weights and scaling factors helps in preservation of the original values. The basic purpose is to imbibe the spatial information of high-resolution data in the spectral realm of low-resolution multi-spectral data, keeping in mind the requirement of minimum loss of original information from either of the two data sets.

The paper presents an objective evaluation of three image fusion techniques based on IHS, discrete wavelet transfer (DWT) and Additive Wavelet. From visual aspect, the spatial and spectral resolutions of all the results have been enhanced compared with the source multi spectral images. The result of fusion using IHS (both cylindrical and triangular models) fusion has more spatial resolution as compared to the other fusion methods, although they exhibit color distortion for vegetation cover. The DWT fusion gave the optimum spectral enhancement when the level used was three. At higher levels, the color fades gradually. The IHS with DWT causes color distortion in the fused image whereas the additive wavelet based fusion method preserves the original spectral content to some extent.

Importance of Image Fusion

The image fusion in remote sensing is primarily intended for presentation to a human observer for easier and enhanced interpretation. Therefore the perception of the fused image is of paramount importance when evaluating different fusion schemes. The main objectives of image fusion are improved image reliability (by redundant information) and also improved image capability (by complementary information). Some generic requirements can be imposed on the fusion result.

1. The fused image should preserve as closely as possible all relevant information contained in the input images
2. The fusion process should not introduce any artifacts or inconsistencies which can distract or mislead the human observer or any subsequent image processing steps.
3. In the fused image irrelevant features and noise should be suppressed to a maximum extent.

A typical multi-resolution satellite sensor works in several multi-spectral modes, along with panchromatic mode of higher spatial resolution. The additional information of the panchromatic band in combination with the multi-spectral bands, allows the retrieval of maximum image information from the given image data set. Most satellites don't collect high-resolution multi spectral images directly. Hence, the requirement of high-spatial and high-spectral resolution data is not met due to two major technical limitations such as the incoming radiation energy to the sensor, and the data volume collected by the sensor. A pan image covers a broader wavelength range, while a multi spectral band covers a narrower spectral range. To receive the same amount of incoming energy, the size of a pan detector can be smaller than that of a multi spectral detector. Therefore, on the same satellite or airplane platform, the resolution of the pan sensor can be higher than that of the multi spectral sensor. In addition, the data volume of a high-resolution multi spectral image is significantly greater than that of a bundled high-resolution pan image and low-resolution multi spectral image. This bundled solution can mitigate the problems of limited on-board storage capacity and limited data transmission rates from platform to ground [1]. Hence, image fusion is required for sharpening images, enhancing certain features not visible in either of the single data set, detecting changes using multi temporal data, improving geometric corrections and improving classification accuracy and cost saving.

MATERIALS AND METHODS

Image fusion takes place at three different levels:

a) 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.

b) In feature-level fusion, the features are extracted from different types of images of the same geographic area which are then classified using statistical or other types of classifiers.

c) 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 [3]. Fig.1 gives the different levels of image fusion.

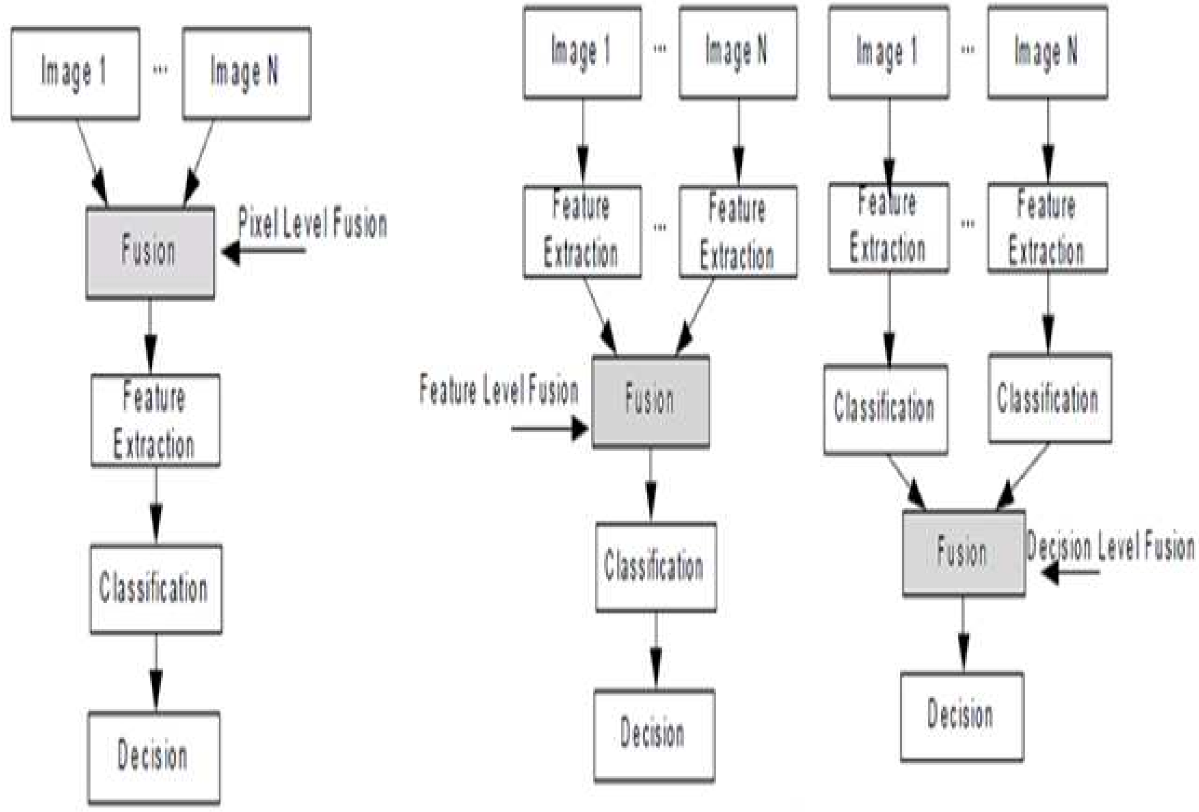

Fig .1 Different levels of image fusion

We have concentrated on the pixel-based fusion which is performed at the level of spectral radiance values and offers minimum of original spectral information.

The above technique requires the input images to be registered with high accuracy of less than half a pixel, since mis-registration can cause artificial colors in features of data, thereby leading to falsifying of interpretation. The image fusion techniques can be categorized into three types, color-related, numerical/statistical-related and a combination of all of them. All color related techniques employ slicing of original data into their respective layers, which can be basic RGB, human perceived IHS, HSV or more scientific luminance–chrominance. This is followed by substitution by a high resolution image in place of one of these channels and a back-transformation of this combination into the original RGB domain. The application specified decides on the choice of image channel to be employed. The statistical method, as indicated by its name, uses a mathematical approach for data integration. It involves addition, multiplication, differencing, and rationings of low and high resolution data prior to their integration. Inclusion of weights and scaling factors helps in preservation of the original values. The basic purpose is to imbibe the spatial information of high-resolution data in the spectral realm of low-resolution multi-spectral data, keeping in mind the requirement of minimum loss of original information from either of the two data sets.

The methods used to merge the information contents of both data sets were the IHS (triangular and cylindrical), Principal Component Analysis (PCA), Brovey's Transform, DWT and additive wavelet. The combined approaches involve integration of IHS and wavelet transformation both statistical as well as color related techniques. One such approach employs the substitution of Principal component 1(PC1) of multi-polarized SAR data instead of intensity component of multi-spectral data.

It should be noted that remote sensing data contain various geometric and radiometric distortions, the rectification of which is a prerequisite to ensure compatibility of data on pixel-by-pixel basis for pixel-based image fusion. Random geometric distortions and unknown systematic geometric distortions are corrected by approximating the polynomials using well-distributed ground control points (GCPs), occurring in the given data set of images. The panchromatic and radio metrically-corrected multispectral data is re-sampled, so that the output false color composite of data is of the same dimension as the corresponding panchromatic image. The Near Infrared (NIR) band of original multi-spectral image was stretched linearly and stacked to produce a false color composite. Few techniques were used to fuse the data and the outputs were subjected to a standard deviation stretch of 1.7 to improve the visual interpretability. The processing was performed using **MATLAB 7.0** installed in the windows environment.

The IHS color transformation effectively separates spatial (I) and spectral (H, S) information from a standard RGB image. It relates to the human color perception parameters. The three bands of a color image are being transferred from the RGB space into the IHS space. The intensity image is then replaced by a high resolution panchromatic image. To have a better fusion quality, the panchromatic image usually needs to be matched to the intensity image before the replacement. After the replacement, the panchromatic image together with the hue and saturation images are transformed from the IHS space into the RGB space, resulting in a fused color image. This process is schematized in **Fig.2.**

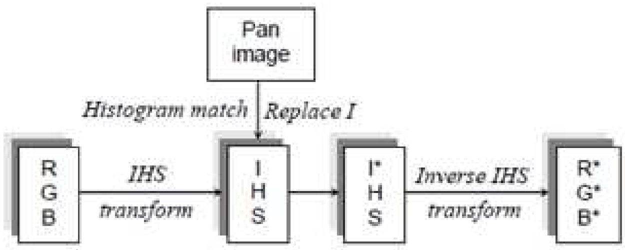

Fig.2: The transformation from the IHS space into RGB space.

The forward IHS transform triangular model is given below.

$$I = \frac{1}{3} I'$$

$$I' = R + G + B$$

B is minimum	R is minimum	G is minimum
$H = \frac{G-I\,B}{I'-3\,B}$, $S = \frac{I'-3\,B}{I'}$	$H = \frac{B-R}{I'-3\,R}+1$, $S = \frac{I'-3\,R}{I'}$,	$H = \frac{R-G}{I'-3\,G}+2$, $S = \frac{I'-3\,G}{I'}$

The corresponding inverse IHS transformation is,

B is minimum	R is minimum	G is minimum
$R = \frac{1}{3}I'(1+2\,S-3\,S\,H)$ $G = \frac{1}{3}\,I'(1-\,S+3\,S\,H)$ $B = \frac{1}{3}\,I'(1-\,S)$	$R = \frac{1}{3}I'(1-\,S)$ $G = \frac{1}{3}\,I'(1+5\,S-3\,S\,H)$ $B = \frac{1}{3}\,I'(1-4\,S+3\,S\,H)$	$R = \frac{1}{3}I'(1-7\,S+3\,S\,H)$ $G = \frac{1}{3}\,I'(1-\,S)$ $B = \frac{1}{3}\,I'(1+8\,S-3\,S\,H)$

Where I is the intensity, H is hue, S is saturation and R, G, and B represents the red, green and blue values respectively.

The IHS cylindrical transform is given by,

$$\begin{pmatrix} I \\ v1 \\ v2 \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & -\frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Where $H = tan^{-1}(\frac{v1}{v2})$ and $S = \sqrt{v1^2 + v1^2}$;

The $v1$ and $v2$ are two intermediate values. The corresponding invrse transformation is,

$v1$= S cos(H) and $v2$= S sin(H) and

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & -\frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{pmatrix} \begin{pmatrix} I \\ v1 \\ v2 \end{pmatrix}$$

The Brovey transform is based on the mathematical combination of the multispectral images and high resolution pan image. It is a simple method to merge data from different sensors, which can preserve the relative spectral contributions of each pixel but replace its overall brightness with the high spatial resolution image. When applied to three multi spectral bands, each of the three spectral components (as RGB components) is multiplied by the ratio of a high-resolution co-registered image to the intensity component I of the multi spectral data. The equation for fusion is,

$$IMG_i = \frac{IMG_{lowi}}{I} IMG_{high}, i = 1, 2 \text{ and } 3.$$

Where IMG_{lowi}, i=1,2 and 3 denote three selected multi spectral band images and IMG_{high} stand for high-resolution image and IMG_i stand for fusion image. The intensity component I is given by,

$$I = (IMG_{low1} + IMG_{low2} + IMG_{low3})/3$$

The fundamental idea of the wavelet-based fusion is to incorporate the low-resolution spectral data on a decomposition level of the high-resolution spatial data, where the resolution of the ground covers matches. This can be done by replacement, addition, or selection of the corresponding coefficients.

The final synthesis of the merged components generates an image that incorporates the spectral information of the low-resolution band and the spatial resolution of the more highly panchromatic band. The **Fig.3** gives the DWT algorithm.

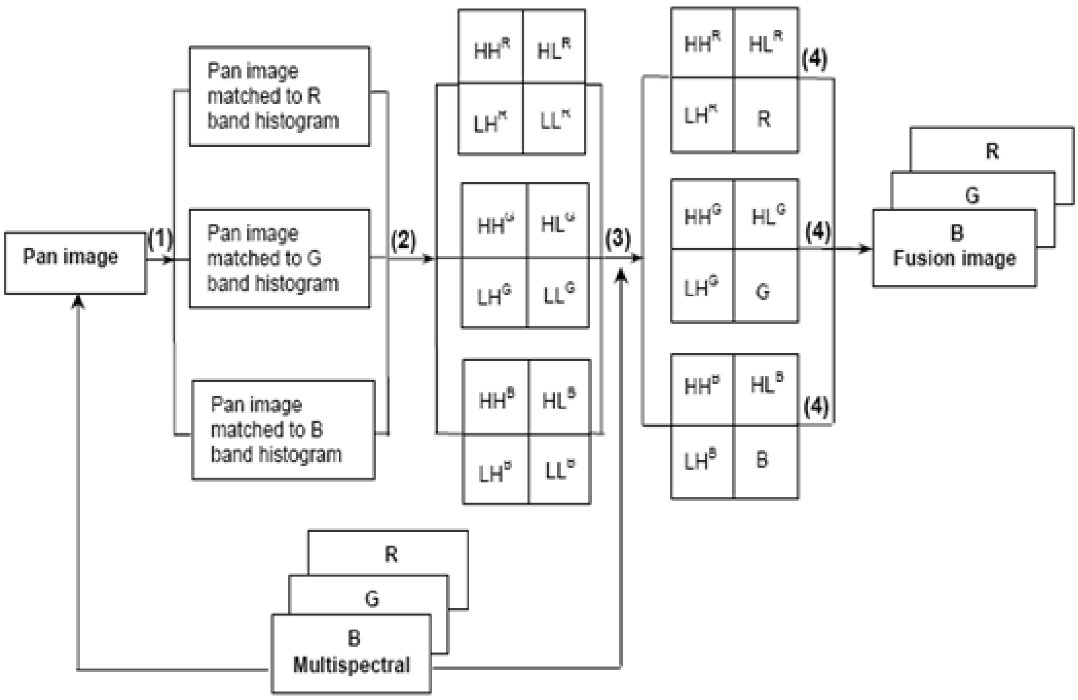

Fig.3 The DWT algorithm

The three new panchromatic images are produced according to the histogram of R, G and B bands of multispectral image. Subsequently, each of the new high-resolution panchromatic images is decomposed into a low-resolution approximation image and three wavelet coefficients, also called detail images, which contain information of local spatial details. The decomposed low-resolution panchromatic images are then replaced by the real low-resolution multispectral image bands (BGR) respectively. In the last step, a reverse wavelet transform is applied to each of the sets containing the local spatial details and one of the multispectral bands (B, G, and R). After three reverse wavelet transforms, the high-resolution spatial details from the panchromatic image are injected into the low resolution multispectral bands resulting in fused high-resolution multispectral bands. In Fig.3, (1), (2), (3) and (4) indicate the processing steps of histogram matching, wavelet decomposition, band replacement and reverse wavelet transform. The R, G and B are three bands of a multispectral image set; and the superscripts R, G and B indicate wavelet decompositions from R, G, or B matched panchromatic images. The LL^R represents an approximation image of pan image according to R band histogram at a lower resolution level. The HH^R, HL^R and LH^R represent corresponding wavelet coefficients (or detail images) in diagonal, horizontal and vertical directions. [4].

DWT using “wfusing”

Additive wavelet-based image fusion method is shown in Fig.4

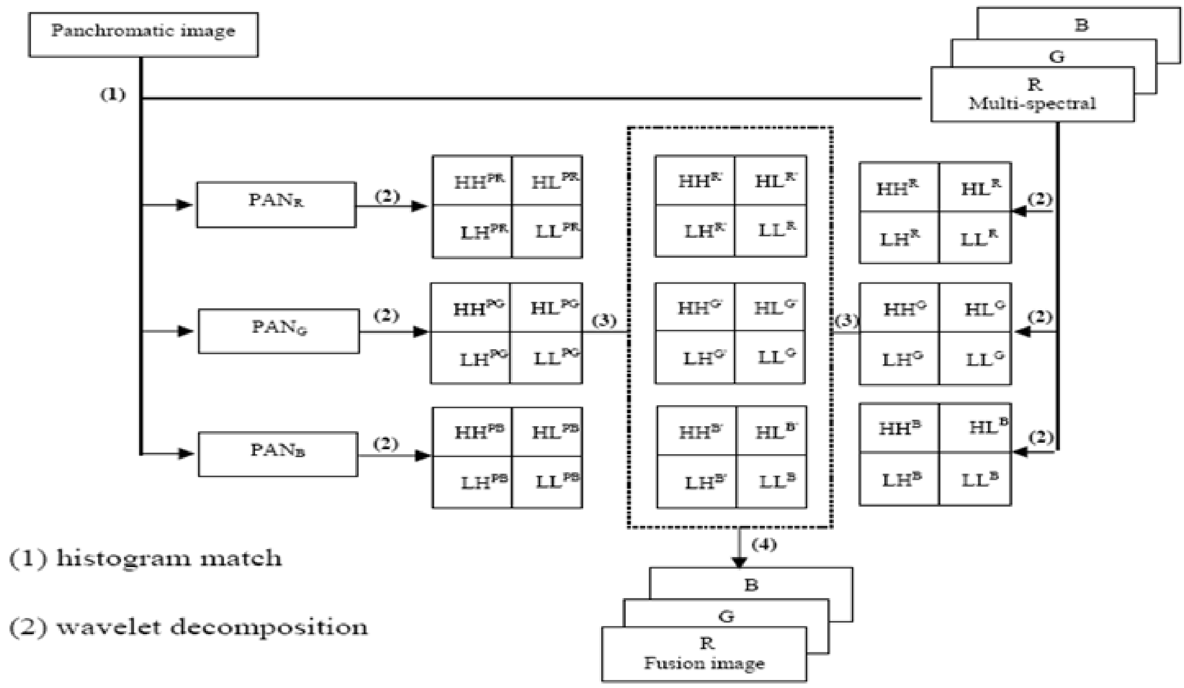

Fig.4 Schematic diagram of additive wavelet based image.

The whole process can be divided into four steps:

(1) Once the panchromatic image and multispectral image has been registered, apply histogram match process between panchromatic image and different bands of the multispectral image to obtain three new panchromatic images (PANR, PANG, and PANB).

(2) Use the wavelet transform to decompose new panchromatic images and different bands of multispectral image twice, respectively.

(3) Add the detail images of the decomposed panchromatic images at different levels to the corresponding details of different bands in the multispectral image to obtain the new details component in the different bands of multispectral image.

(4) Perform an inverse wavelet transform on the bands of multispectral images, respectively, and obtain the fused image.
Integration of substitution method with wavelet method has the following steps. Fig.5 below Represent the basic steps for substitution method for wavelet transform.

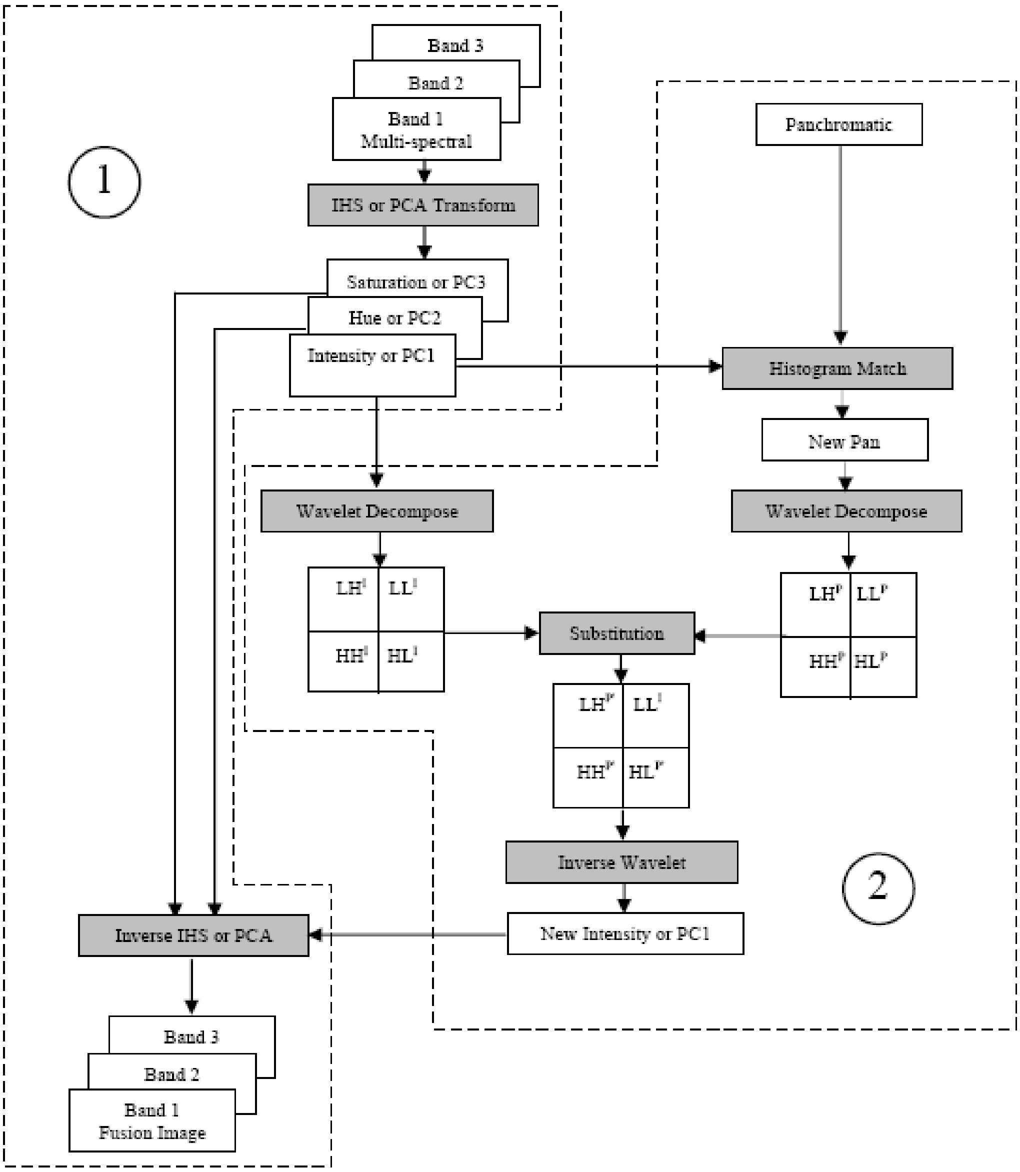

Fig.5: Basic steps for IHS method for wavelet transform.

(1) Transform the multispectral image into the IHS or PCA components.
(2) Apply a histogram match between panchromatic image and intensity component or PC1, and obtain new panchromatic image.
(3) Decompose the histogram-matched panchromatic image and intensity component or PC1 to wavelet planes respectively.
(4) Replace the LL^P in the panchromatic decomposition with the LL^I of the intensity or PC1 decomposition, add the detail images in the panchromatic decomposition to the corresponding detail image of the intensity or PC1 decomposition and obtain LL^I, $LH^{P'}$, $HH^{P'}$ and $HL^{P'}$. Perform an inverse wavelet transform, and generate a new intensity or new PC1 component.

(5) Transform the new intensity together with the hue, saturation components, or new PC1 with PC2, PC3, back into RGB space.

The PCA algorithm calculates the principal components of an image. The PC1 represents the largest variance, which typically resembles an intensity image; each of the remaining components represents successively smaller amounts of variances. The technique used is similar to the IHS merge. Three or more Multispectral Images bands are input to the PCA algorithm. Any of the resulting components can then be replaced by the panchromatic sharpening band. The final step is an inverse PCA [7]. The PCA de-correlates the image data. The advantage is that an arbitrary no. of bands may be used as against IHS which is limited to only three bands. Fig.6 below gives the PCA algorithm to calculate the principal components of the image.

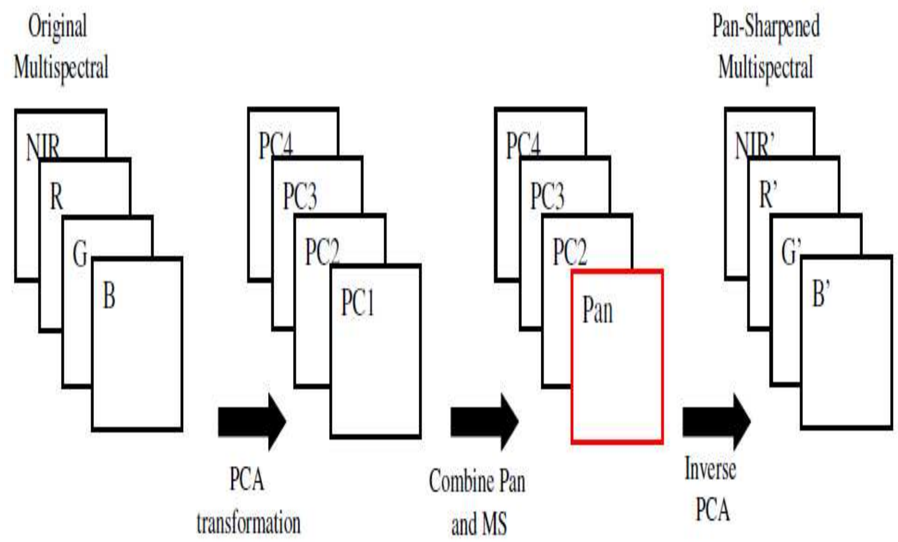

Fig.6: PCA Algorithm

RESULTS AND DISCUSSION

All methods used in our analysis assume that the images are geometrically registered and radio metrically calibrated. Analysis and comparison are based on spectral and spatial characteristics, and is done both visually and quantitatively. From visual aspect, the spatial and spectral resolutions of all the fusion images are enhanced compared with the source multi spectral images. The results of fusion using IHS (both cylindrical and triangular models) fusion have more spatial resolution as compared to the other fusion methods, although they exhibit color distortion for vegetation cover. The DWT fusion gives the optimum spectral enhancement when the level used was three. At higher levels, the color fades gradually. The IHS with DWT causes color distortion in the fused images, whereas the additive wavelet based fusion method preserves the original spectral content to some extent.

The calculated parameters for IHS, Brovey's Transform and DWT using substitution and additive with DWT are listed in Table 1**.** The mean value represents the average intensity of an image. In Table1, the mean values of IHS (cylindrical and triangular), and Brovey are approximately identical to original pan images which has better spatial effect, whereas DWT integrated with IHS and additive wavelet are approximately identical to the original multispectral image. The information entropy measures the richness of information in an image and reflects the amount of information of the panchromatic image incorporated into multi spectral images during merging. Analysis carried out verifies that DWT using substitution method with wavelet method provides more detailed spatial information and simultaneously preserves the richer spectral content of the original multi spectral images than other fusion methods.

Table 1: Obtained values by different fusion methods

Methods	Mean	Entropy
Original Multispectral Image	64.7360	7.3470
Panchromatic Image	70.3245	7.1726
IHS Using Triangular model	70.3191	7.3302
IHS using Cylindrical model	70.4712	7.3504
Brovey's Transform	70.2845	7.3257
DWT "wfusing" function	53.2266	7.0214
DWT using Integration of substitution method with wavelet method	64.7737	7.3528
DWT using Additive – wavelet based image fusion	64.9159	7.2666

CONCLUSION

The pixel level fusion of low resolution multispectral image and high resolution panchromatic image was implemented using various fusion techniques. Comparative analysis is conducted on a set of multi spectral images and a panchromatic image. The effectiveness of these algorithms has been evaluated quantitatively and qualitatively.

It was found that there is a color distortion appearing in the fused images using IHS algorithm. There is a trade off in every method in spatial and spectral resolution.

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