

Performance Analysis And Working Principle Of Different Image Fusion Models For Remote Sensing Data

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Abstract:

Image Fusion is a process of combining multiple input images into a single output image. The role of Image Fusion is demanding in many domains like Medical, Satellite, military, Multi focus etc. In remote sensing applications, the increasing availability of space borne sensors gives a motivation for different image fusion algorithms. Several situations in image processing require high spatial and high spectral resolution in a single image. The remote sensors extract desired information about the Earth's surface structure and content, which is derived from different portions of the electromagnetic spectrum at a distant location vary in spectral, spatial and temporal resolutions. The limitation of satellite sensors is that they cannot directly collect high-resolution multispectral images. However, they provide PAN and MS sensors simultaneously. So there is need for image fusion. Fused products have more advantage than normal product. In this paper, different image fusion methods and their performance have been analyzed for choosing the right model for image fusion.

KEY WORDS: Remote sensing, Image Fusion, Spatial Resolution, Spectral Resolution

1. Overview Of Image Fusion Process

The most generally used remote sensing image fusion models are listed and described below; working and results of each fusion model is proposed in the following sections.

- Intensity-Hue-Saturation(HIS) transformation fusion model
- Brovey Transform (BT) fusion model
- Principal Component Analysis (PCA) fusion model
- Guided fusion model
- Non Subsampled Contourlet Transform (NSCT) fusion model

Intensity-Hue Saturation (HIS) model and Principal Component Analysis (PCA) Model are falling in the component substitution category. The main principle of the CS category is distinguishing the spatial information from the spectral information in MS image by using linear transform and then replacing the spatial information by PAN image. The spatial component is obtained by using a linear transform and PAN image, which replaces the spatial component, it must have similar spectral information and reduces of spectral distortion in output image.

Based on the CS techniques, the fusing of MS and PAN image has following general steps:

- (i) In the first step, upsampling the MS image to the PAN image size.
- (ii) Apply linear transform for obtain the desired component in MS image.
- (iii) Substitute the matched PAN image histogram to desired component.
- (iv) Replace the desired component with high spatial information by histogram matched PAN image.
- (v) Applying of Back transformation to component for generate the fused image.

The CS method achieves the result in fast and easy manner but it has some spectral distortions because of MS and PAN image dissimilarities.

The fusion model of Brovey Transform (BT) is the modulation based fusion technique. Commonly modulation based fusion technique is achieved by multiplying a MS image with high resolution PAN image.

2. Intensity-hue-saturation (HIS) Transformation Fusion Model

For image fusion process, the original RGB color space model is not used because of their image channels correlation is not clear. But HIS transformation model gives a good color property for each channel of HIS. HIS color channels such as intensity (I), hue (H), and saturation (S). Here Hue is the color predominant wavelength, saturation is the purity or total amount of color white light and intensity is the total amount of light, it reaches the human eye. Hue expressed as an angle. Hue typically has 0 degree Red, 120 degree Green and 240 degree Blue. The hue follows the apparent color continuum from Red (0 degree) to Blue (240 degree). For eye vision is using non-spectral light ranging in 240 degree to 360 degree light range. Saturation defined as the duration of the segment point joining to the center of the color circle. Obtaining of intensity I_c , vector1 U_{1vec} and vector2 U_{2vec} from each pixel of RGB color space values, with coefficients are connected to image cube geometry. Here, U_{1vec} and U_{2vec} are hue and saturation Cartesian components. The transform of the IHS distinguishes the spatial information component I from the spectral details defined by components H and S. The fusion process as follow as:

- (i) In that, first MS image is up sampled to the PAN image size.
- (ii) RGB color of MS image is transformed into HIS color space; where component I denote the spatial information in order to component H and S denote image color information.
- (iii) Next, replace the I component by the histogram matched PAN image with high spatial information.

- (iv) Finally, inverse transform is applied to combination of generated PAN image, the hue and saturation components for reconstruct the fused RGB MS image.

Thus, based on HIS transform obtained the fused result with high spatial information and reduced spectral distortion. In table 1 has shown the quality metric assessment to data.

Table 1: Quantitative Evaluation of the LANDSAT 7 ETM+ data 1 – based on HIS

Metrics	CC	SD	Entropy	SF	FMI
Data 1	0.9988	15.802	5.8667	0.6086	0.9172

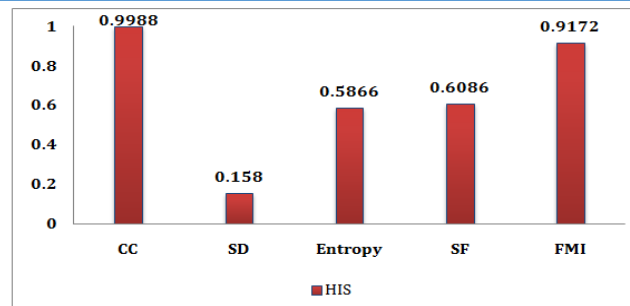


Fig 1. Quantitative evaluation of HIS fusion results with LANDSAT 7 ETM+ data 1

3. Brovey Transform (Bt) Fusion Model

Sharpening MS image is obtained by using of ratios of the Brovey Transform (BT). As BT has been designed to generate RGB pictures, the terminology is restricted to only three bands.

BT's underlying concept comes from the ability to utilize the simplest mathematical procedures. Practically all variations of arithmetic operations were used in the fusion of MS and PAN images, including addition, multiplication, standardized division, ratios and subtraction. These mathematical operations are applied to MS and PAN bands which have been merged to achieve a better fusion effect in various ways. These models presume that the correlation between the PAN and MS each bands is high. Brovey transform, normalized color transformation, and multiplicative models are the popular arithmetic combination methods.

Only multiplication is unlikely to distort the colors of the four possible arithmetic methods by transforming intensity into a panchromatic image. In the multiplicative system each pixel is multiplied by the equivalent pixel of the PAN data in each MS data l band. The square root of the corresponding dataset is taken to remove the increased light or brightness. The multiplicative data set square root reflects the mixed spectral characteristics of both sets. The formula of the fusion algorithm is as follows:

$$Z_{l(x,y)} = \sqrt{S_{l(x,y)} R_{(x,y)}} \quad (1)$$

So this algorithm is a basic multiplication of each band of MS with PAN image. The algorithm's benefit is clear and quick. However, it produces spectral bands with a higher similarity by averaging the same details across all bands, which implies that it changes the original image data spectral characteristics.

This model is simple in terms of computation; generally it is the fastest model and needs the least resources from the system. The resulting merged image however does not fully retain the input MS image spectral characteristics. The component of intensity is increased, thereby making this technique ideal for illustrating urban features that appear to represent higher components in a visible image and near infrared image. Table has shown the quality metric assessment to data 1

Metrics	CC	SD	Entropy	SF	FMI
Data 1	0.9982	12.323	5.5138	0.5560	0.9067

Table 2: Quantitative Evaluation of the LANDSAT 7 ETM+ data 1 – based on BT

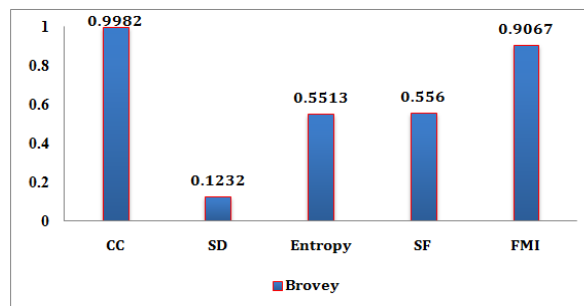


Fig.2. Quantitative evaluation of BT fusion results with LANDSAT 7 ETM+ data 1

4. Principal Component Analysis (PCA) Fusion model

Principal component analysis (PCA) transform is one of the categories of component substitution. PCA mostly utilized in many applications such as signal processing, statistics and etc. Based on the application field, PCA is said as the Karhunen-Loeve transform (KLT), Hotelling transform (HT) or proper orthogonal decomposition (POD). Also PCA is a way to dimensionality reduction which means reduce the bigger dataset dimensionality into smaller dataset by sorting of all the information. Principal component analysis has some common steps as follows:

- (i) Dataset standardization
- (ii) Covariance matrix construction
- (iii) Decomposition of covariance matrix into eigenvector and Eigen values
- (iv) Sorting of Eigen values
- (v) Choose the large Eigen values (principal components)
- (vi) Construction of feature vector (eigenvectors)
- (vii) New dataset derivation

PCA is the simplest way to compute the eigenvector, based on multivariate analyses. This is also used as a method for creating statistical models in data studies. It is strongly connected with the factor analysis. PCA transforms correlated variable into uncorrelated variables to render it more accurate. In fact, fast computation is done by reduce the dimensionality. Dimensions were minimized by taking the principal component's highest Eigen value variable.

The mathematical procedure of PCA utilize the orthogonal transform to transform a set of observations of possibly correlated variables into set of linearly uncorrelated variables said as principal components. It determines the dataset compact and optimal representation. Generally, the highest possible variance is accounted to the first principal component P_{c1} that means the specific information like spatial one is localized in first principal component. Conversely, the following components are obtained with the common information, with decreasing of variance like spectral information. In PCA the variance is retained that means input variables cumulative variance is equal to the all components of sum of the variance.

Fast Fourier Transform (FFT), Discrete Cosine Transform (DCT) and wavelet has fixed set of basis vectors but PCA have dataset based basis vectors. From the set of source images, extracting of spatial and spectral information that characteristic is the motivation for the remote sensing image fusion by PCA. Generally in PCA, first covariance matrix eigenvectors and Eigenvalue are generated then sorted done by decreasing of Eigenvalue.

PCA fusion model is based on principal component transform (PCT), which transforms an MS image with correlated bands into group of uncorrelated components. MS image first component similar to the PAN image. Hence, it is replaced for fusion by the high resolution PAN image. The PAN image needs to be matched with the first component of MS image, before the replacement. By performing an inverse PCT the PAN image is merged into the low resolution MS bands. The algorithm works replacing the MS image spatial component with the PAN image helps to integrate spatial features of the PAN image into the MS image. PCA based fusion model is summarized as follows:

- (i) First, MS image is transformed by PCT. In the transformation MS image is arranged into column vector. Then variance and co-variance matrix are generated to MS column vector. After that, Eigen

values and eigenvectors are computed from co-variance matrix. At last MS image first principal component is obtained from eigenvectors is similar to largest Eigen value.

- (ii) Second, PAN image histogram matched with the first principal component of MS image. This is for compensate the spectral differences among them.
- (iii) Third, MS image first principal component is replaced by the high resolution histogram matched PAN image.
- (iv) Finally, fused MS image is generated by inverse PCT.

Thus, PCA fusion model based we obtained the fused result with high spatial information. Table shows the quality metric assessment to data 1

Table 3: Quantitative Evaluation of the LANDSAT 7 ETM+ data 1 – based on PCA

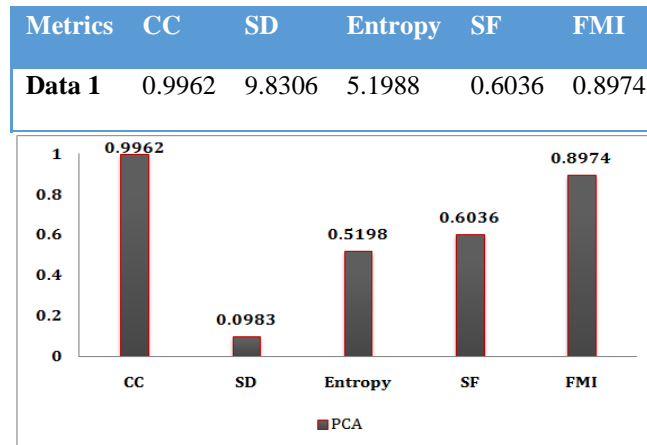


Fig.3. Quantitative evaluation of PCA fusion results with LANDSAT 7 ETM+ data 1

5. Guided Fusion Model

Guided filtering based fusion model is implemented by combining the characteristics of original source image and guidance image. When choosing the original and guidance images accurately, integration of the characteristics of both images is feasible. In this portion, we study the guided filtering algorithm briefly; then we examine the properties of the guided image filtering mechanism and fusion mechanism.

Guided filter compute the filtering output that follows a local linear model between the filter output P and guidance image F in a local window ω_l centered at pixel l.

$$P_k = c_1 F_k + d_l, \quad \forall k \in \omega_l \quad (2)$$

where c_1 and d_l are denote as linear coefficients; In small square local window ω_l with $(2h + 1) \times (2h + 1)$ radius, linear coefficients are consider as constant. Based on guidance image F edge property, the output filter P has an edge which means local linear model guarantees to generate $\nabla P = c \nabla F$.

The main aim of the guided filtering fusion model is to generate the new MS image with high spectral and spatial properties. Working steps is described as per below:

- (i) The MS image S is resampled and registered to PAN image R size.
- (ii) Estimates the weights w_k is easily by reducing the residual sum squares (RSS) as follow as:

$$RSS(w_k) = \sum_y \sum_z \left((R(y, z) - \sum_{k=1}^4 w_k S_k(y, z))^2 \right) \quad (3)$$

After that, the low resolution PAN image \tilde{R} is obtained by eq (3.23).

$$\tilde{R} = \sum_{k=1}^4 w_k S_k \quad (4)$$

where \tilde{R} is denote the low resolution PAN image and w_k is denote the weight factor for $S_k(y, z)$ k – th band, that is constant to given band.

- (iii) Every S_k band ($k = 1,2,3,4$) is used as the guidance image to guide the low resolution PAN image \tilde{R} filtering process and filter output $S'_k(k = 1,2,3,4)$ is computed as per below:

$$S'_k = gf(S_k, \tilde{R}), k = 1,2,3,4 \quad (5)$$

where $gf(m, n)$ is the guided filtering process, and m is the guidance image and n denote the input image.

- (iv) The fusion result Z_k is computed by extraction of PAN image spatial information and extracted spatial information introduce into the resampled MS image S_k based on the weight $\omega_k(y, z)$. It can be obtained as follow as:

$$Z_k(y, z) = (R(y, z) - S'_k(y, z)) \times \omega_k(y, z) + S_k(y, z), k \in \{1,2,3,4\} \quad (6)$$

$$\omega_k(y, z) = \frac{1}{\sqrt{\sum_{(a,b) \in w_{(y,z)}} (S_k(a, b) - R(a, b))^2}}, k \in \{1,2,3,4\} \quad (7)$$

where $Z_k(y, z)$ is denote the fusion result, $R(y, z)$ is denote the input PAN image, $S_k(y, z)$ is express the resampled MS image, $S'_k(y, z)$ is denote the filter output, $\omega_k(y, z)$ is denote the weight to k - th MS band in the position of (y, z) , $w_{(y,z)}$ is the local square window at (y, z) , (a, b) is denote the pixel in $w_{(y,z)}$, k is denote the MS image band number and total bands of MS image i.e. 4.

Finally, we conclude in guided filtering which includes the resampled spectral information of S_k band (guidance image) and simulated PAN band \tilde{R} (input image). So the filter output band S'_k extracts the both S_k and \tilde{R} structure information. This method based fusion result has less spectral distortion.

Three important parameters used in this work i.e. local windows radius h , guided filter regularization parameter ϵ , local windows radius H for finding weights Table shows the quality metric assessment to data 1 and data 2.

Table 4: Quantitative Evaluation of the LANDSAT 7 ETM+ data 1 – based on Guided

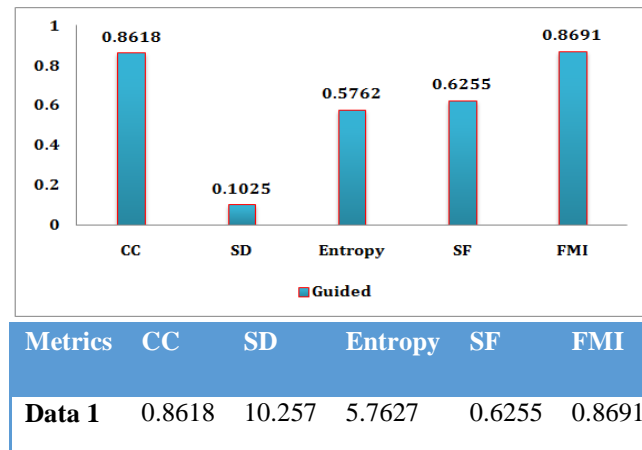


Fig.4 Quantitative evaluation of Guided fusion results with LANDSAT 7 ETM+ data 1

6. NON SUBSAMPLED CONTOURLET TRANSFORM (NSCT) FUSION MODEL

The NSCT splits the two-dimensional (2D) signal into many components that are shift invariant. The two-dimensional signal is decomposed into different decomposition stages called the Non Subsampled Pyramid Structure (NSPS). The Non Subsampled Directional Filter Bank (NSDFB) is used to receive directional components at the high frequency level . The filter bank separates the 2D frequency. Multi-scale properties are achieved by NSPS, and the directionality is provided by NSDFB.

The NSCT depiction contains the following properties:

- (1) Multi-resolution property
- (2) Multi-direction property
- (3) The Shift Invariant property
- (4) Regularity property
- (5) Redundancy property $K + 1K$ is level number

With the aid of Multi – Resolution Analysis (MRA), the proposed NSCT preserves the trade-off between the spectral and spatial resolutions to a reasonable extent. The wavelet drawbacks are solved using non subsampled contourlet transform. The NSCT helps retain the intrinsic structural information while decomposing and recreating the components of the image. The experimental results and analysis demonstrate that the proposed NSCT is superior to the wavelet-based and other conventional methods. In fusion result of MS and PAN image by using NSCT model is illustrated.

Table 5: Quantitative Evaluation of the LANDSAT 7 ETM+ data 1 – based on NSCT

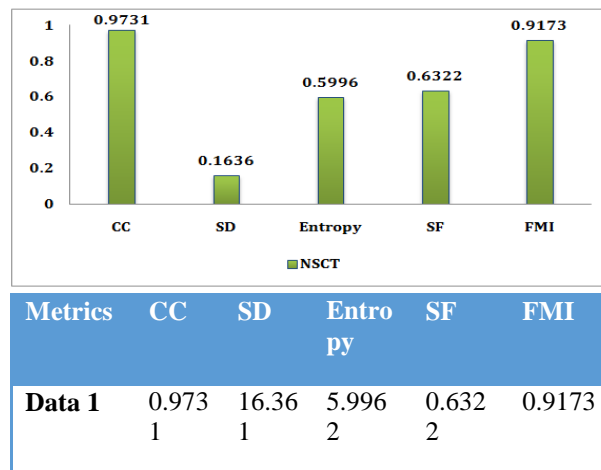


Fig.5 Quantitative evaluation of NSCT fusion results with LANDSAT 7 ETM+ data 1

Here, we propose some quality metrics like CC, SD, Entropy, SF and FMI to quality analysis of fused image. CC is denote the correlation coefficients, SD is the standard deviation, SF is the spatial frequency and FMI is the fusion mutual information.

7. SOURCE OF DATASET

From U.S. Geological service (<http://usgs.gov>) the data was collected. We can Searched and downloaded these data easily from <http://earthexplorer.usgs.gov>. Original source images are from Landsat Enhanced Thematic Mapper Plus (LANDSAT 7 ETM+). In our dataset, we give small scenes from the original images. Each scene has a data file which is multispectral and panchromatic. We neglected the thermal infrared bands and swapped the order of bands 1 and 3. MATLAB software is used to process and evaluate the remote sensing images. Collected data location is taken in one format that as follows:

‘P’ PATH ‘R’ ROW, YEAR MONTH DAY, X, Y, WIDTH, HEIGHT

The X and Y positions at the bottom left of the original image are offsets from the origin. The location format is illustrated as follows,

P091R083, 20001006, 4188, 802, 400,400

Above line describes the source images are obtained on path 91 and row 83 on 2000/10/06. The crop field begins from original image’s bottom left hand corner at 802 pixels right and 400 pixels up and has a width and height of 400 pixels.

The two sample data used to our evaluation which location as follows:

Sample Data-1 location:

P034R032, 20010924, 6400, 628, 400, 400

Sample Data-2 location:

P090R083, 20000913, 4504, 6157, 400,400

There are a number of methods for multispectral visualization. Each will highlight different properties of the image. Here we list common band combinations.

R,G,B	Description
1,2,3	Natural Color
4,3,2	False Color

4,5,3

Long Bands

7,4,2

Green Vegetation

8. COMPARATIVE ANALYSIS

This segment reveals the comparative analysis of fusion models such as Intensity-Hue-Saturation (HIS), Brovey Transform (BT), Principal Component Analysis (PCA), Guided Filtering (GF) and Non-subsampled Contourlet Transform (NSCT) models. Based on the above table quality Analysis results, we concluded the NSCT is the superior model than the others.

Table 6: Quality analysis of the LANDSAT 7 ETM+ data 1 with different models

9. CONCLUSION

Finally different techniques and models were presented in this paper with a review from various remote sensing image fusions. The most commonly used image fusion techniques like Intensity Hue Saturation (IHS), Brovey, Principal Component Analysis (PCA), Guided and Non sub sampled contourlet transform (NSCT) are explained in detail. Evaluation of quality metric assessment proves that quality of fused image is different from other models. Combining multiple fusion technique to develop the novel remote sensing fusion is the future scope of research.

Method	HIS	Brovey	PCA	Guided	NSCT
CC	0.9988	0.9982	0.9962	0.8618	0.9731
SD	15.802	12.323	9.8306	10.257	16.361
Entropy	5.8667	5.5138	5.1988	5.7627	5.9962
SF	0.6086	0.5560	0.6036	0.6255	0.6322
FMI	0.9172	0.9067	0.8974	0.8691	0.9173

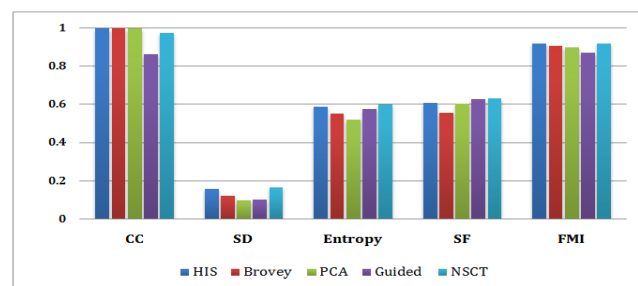


Fig.6 Fusion Results of LANDSAT 7 ETM+ data
1. (a) PAN data. (b) MS data. (c) HIS. (d) Brovey. (e) PCA. (f) Guided. (g) NSCT.

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