Remote sensing image fusion can be used to highlight the information, useful for integrating a high spectral resolution image with a high spatial resolution image, to eliminate or suppress irrelevant information, to improve the quality of image for target recognition, thereby increasing the reliability of interpretation and reduce ambiguity and improve the classification to expand its application and effectiveness. Four pixel-level fusion algorithms of remote sensing images, Brovey Transform, Principal Components Transform (PCA), Multiplication Transform (MLT), High-Pass Filer Transform (HPF), have been used to fuse multispectral image and panchromatic image. And the four fused images have been analyzed and evaluated qualitatively and quantitatively by the amount of spectral information and spatial information maintained in the fused images. Then, the methods are ranked according to the conclusions of the visual analysis and the results from quality budgets.

Keywords – Image Fusion, HPF, PCA, MT, BT.

1. INTRODUCTION
Remote sensing image fusion is a technology that can combine many images with different resolution to generate a new image. It is not a simple compound between the data, while it emphasis on information optimization to highlight the useful information, eliminate or suppress irrelevant information and improve the image features for target recognition, thereby to increase the reliability of interpretation and reduce ambiguity.

Image fusion takes place at three different levels: pixel, feature, and decision. 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.

Image fusion at pixel level means fusion at the lowest processing level referring to the merging of measured physical parameters. It uses raster data that is at least co-registered but most commonly geocoded. The geocoding plays an essential role because misregistration causes artificial colors or features in multisensor data sets which falsify the interpretation.
later on. It includes the resampling of image data to a common pixel spacing and map projection, the latter only in the case of geocoding.

2. IMAGE FUSION TECHNIQUES

A variety of data fusion techniques are devoted to merge MS and PAN images which exhibit complementary characteristics of spatial and spectral resolutions[1]. Such an application of data fusion is often called Pan sharpening. Several researchers have attempted to use different types of satellite images to address the data fusion problem. Several procedures of data fusion have been proposed which could aid in updating resource inventories. These methods include modified Brovey transform (BT), Principal component analysis (PCA), Multiplicative Transform (MT), and High Pass Filter (HPF).

It is worth mentioning here that accurate spatial registration of the two original images is essential for most data fusion methods. This necessitates the use of geometric rectification algorithms that register the images to each other or to a standard map projection.

A. Principal Component Analysis

The major goal of this method is to retain the spectral information of the multispectral images [2]. It is assumed that:

- PC-1 contains only overall scene luminance; all inter-band variation is contained in the other PCs, and
- Scene luminance in the Short Wave Infra Red (SWIR) bands is identical to visible scene luminance.

With the above assumptions, the forward transform into PCs is made. PC-1 is removed and its numerical range (min to max) is determined. The high spatial resolution image is then remapped so that its histogram shape is kept constant, but it is in the same numerical range as PC-1. It is then substituted for PC-1 and the reverse transform is applied. This remapping is done so that the mathematics of the reverse transform do not distort the thematic information.

B. Multiplicative Technique

The algorithm is derived from the four component technique of [2]. It is argued that of the four possible arithmetic methods to incorporate an intensity image into a chromatic image (addition, subtraction, division, and multiplication), only multiplication is unlikely to distort the color. First the intensity component is removed via band ratios, spectral indices, or PC transform.

The MT algorithm is based on the following relation

\[
\begin{align*}
DN_R (\text{new}) &= DN_R * DN_{PAN} \\
DN_G (\text{new}) &= DN_G * DN_{PAN} \\
DN_B (\text{new}) &= DN_B * DN_{PAN}
\end{align*}
\]

where \(DN_{R,G,B} = \text{Digital number of the corresponding pixel belonging to the R, G and B bands}
\)

\(DN_{\text{PAN}} = \text{Digital number of the corresponding pixel belonging to the panchromatic band.}\)

\(DN_{\text{new}} = \text{New digital number of the corresponding pixel of the respective band.}\)

This method is computationally simple; it is generally the fastest method and requires the least system resources. However, the resulting merged image does not retain the radiometry of the input multispectral image. Instead, the intensity component is increased, making this technique good for highlighting urban features (which tend to be higher reflecting components in an image).

C. Brovey fusion

Brovey transformation is a relatively simple image fusion in which the phase space of multi-spectral images was divided into color and brightness components and calculated. It was characterized by simplification coefficient of the image conversion process and it maintains multi-spectral data information maximum.

\[
\begin{align*}
R &= (R / (R + G + B)) * I \\
G &= (G / (R + G + B)) * I \\
B &= (B / (R + G + B)) * I
\end{align*}
\]

Where \(R = \text{Red}, G = \text{Green}, B = \text{Blue}, I = \text{Intensity}.\)

\(R, G, B\) channel layer can be any one band of multi-spectral image, because all bands of the red, green, blue channel layer will be composted into the same synthetic images in the end. Brovey fusion is a color transformation of enhance visual effects. It can keep the spectral feature of the low-resolution images.

D. High-Pass Filtering

High-pass filtering fusion adds High-resolution images geometric information into the low-resolution images by-pixel. The result of high-resolution images of high-pass filter corresponds high-frequency spatial
information, namely, extracting high-resolution images of the corresponding high-frequency components of spatial information by high-pass filter. This kind of spatial filter removes most of the spectral information, and then adds high spectral resolution images into high-pass filter results to form the fusion images which high-frequency feature information is highlighted.

3. EVALUATION CRITERIA FOR IMAGE FUSION TECHNIQUES

The evaluation process consist of

- Visual Interpretation.
- Quality Assessment

There are two types of evaluation criteria for fused image: subjective evaluation and objective evaluation. Subjective evaluation is subjective and uncertain to a certain extent [3]. The objective evaluation for multi-source image fusion was carried out by using statistical parameters of the image. They are two kinds of requirement on image fusion, which are not only to increase the spatial resolution of fused image but also to keep the spectral information as much as possible. However, these two requirements are largely incompatible. The objective evaluation of indicators often used in recent years can be divided into two types: one is used to reflect the spectral information, such as the correlation coefficient, RMSE. The other is to reflect the spatial information, such as the standard deviation and entropy.
3.1 Visual Analysis

The resulting images obtained from different conventional techniques had erosion scars and some of the deposition areas enhanced related to the other targets in the images. PCA looks much closer to Multispectral band in color hence look more vivid in PCA than BT. Further, PCA is brighter than BT and MT, MT looks dull and smoky. Next to PCA it is the BT which is closer to Multispectral data. In brightness retaining quality too the fusion technique is found to be bright and better preserving the original Multispectral details. When all the visual evaluation are put together, the PCA is found to be bright and better in preserving the original Multispectral details; the BT ranked the second and MT stand in the last in retaining spectral quality. However for these approaches one can verify that it was not possible to obtain a good detail. For example, grass, natural fields and vegetation cover in the early growing stage were not well discriminate. It was also possible to notice a defocusing in the images, which made the erosion scars look like stains instead of linear feature.

Among the conventional techniques, it was observed that PCA seems to give the best result of image fusion. Due to preservation of spectral characteristics, it was possible to discriminate more precisely other targets existing in the image. After the spatial resolution enhancement, it was also possible to identify several small features of landslides and the color scheme is also as good as the original image that were not identified using other fusion approach.

3.2 Quality Assessment

Quality refers to both the spatial and spectral quality of images. Image fusion methods aim at increasing the spatial resolution of the MS images while preserving their original spectral content. The evaluation of the fusion results is based on the quantitative criteria including spectral and spatial properties and definition of images. In this paper, four evaluation criteria are used for quantitative assessment of the fusion performance. The spectral quality of fused images is evaluated by the Spectral discrepancy, Correlation Coefficient (CC), RMSE. For the spatial quality assessment, the Entropy, Standard Deviation (SD) are applied and the results are analyzed[5].

a) Spectral Quality Assessment

The basic principle of spectral fidelity is that the low spatial frequency information in the high-resolution image should not be absorbed to the fusion image, so as to preserve the spectral content of original MS image. The indexes which can reflect the spectral fidelity of fusion image include.

➢ Correlation Coefficient (CC):

CC measures the correlation between the original and the fused images. The higher the correlation between the fused and the original images, the better the estimation of the spectral values. The ideal value of correlation coefficient is 1.

\[
CC = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \tag{3}
\]

Where \(n\) is the number of pixels, \(x_i, y_i\) are the grey values of homologous pixels in the two images (bands under comparison), and \(\bar{x}\) and \(\bar{y}\) are the mean grey values of both the images.

➢ Root Mean Square Error (RMSE):

RMS error as proposed by Wald (2002), which is computed as the difference of the standard deviation and the mean of the fused and the original image. The formula for RMSE is:

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{mn} (f_i - f'_i)^2}{mn}} \tag{4}
\]
Where n and m are number of pixels, \( f_i \) represents the true MS image intensity value at the ith pixel and \( f'_i \) is the corresponding fused MS image intensity.

b) Spatial Quality Assessment

The basic principle of spatial fidelity is that the high spatial frequency information absorption is that the enhancement of resolution and increasing of information of the fused image relative to the original MS image. The indexes which can inflect the spatial fidelity of fusion image include:

- **Entropy:**

The Entropy can determine the average information included in the image and reflect the detail information of the fused image. Commonly, the greater the Entropy of the fused image is, the more abundant information included in it, and the greater the quality of the fusion is. According to the information theory of Shannon, The Entropy of image is:

\[
H(x) = -\sum_{i=0}^{C-1} p(i) \log_2 p(i) 
\]

(5)

- **Standard Deviation (SD)**

It is an important index to a weight the information of image; it reflects the deviation degree of values relative to the mean of image. The greater SD is, the more dispersible the distributing of the gray grade is in the statistical theory.

\[
\sigma = (1/n) \sum (MS_{i,j} - MS_{mean})^2 
\]

(6)

Where \( \sigma \) is the SD, MS is the multi-spectral data, n is the bands of MS.

4. EXPERIMENT DATA AND ANALYSIS OF FUSION RESULTS

4.1 Experiment Data

The image fusion techniques applied on the IRS P5 and P6 satellite images. IRS-P6 multispectral image has three 5.8-m resolution spectral bands (Green, Red, NIR) and resolution of IRS-P5 panchromatic image is 2.5-m as shown in Figure2. The study area is chosen to cover different terrain morphologies from the Mysore Region of Karnataka state, India. Figure 2 shows an example of the fused IRS-P6 MS and IRS-P5 pan images using four fusion algorithms, such as PCA, Brovey, MT and HPF algorithms.

4.1.1 Analysis of Fusion Results

Initial qualitative visual inspections reveal that all the fused images have better qualifications than original non-fused images. The sharpness of the fused images has been significantly enhanced. The further quantitative evaluation can be done with above criteria.

a) Maintenance of spectral information

Correlation coefficients of various fusion algorithms are from 0.3398 to 0.6376 (Table 1). The smallest is that of the HPF fusion, which indicate that there is big spectral distortion of fused image compare to original image. The Correlation coefficient of the Brovey, PCA, MT and HPF fusion is at the same level, the difference between them is small, indicating that the four fusions of multi-spectral image to have changed spectral information in a great extent. The biggest of the correlation coefficient is that of MLT fusion, followed by that of PCA fusion, which shows that the fused images by using above two fusions are similar to the original multi-spectral images to a great extent, the spectral information maintenance to multispectral images is the best.

b) Maintenance of spatial information

The standard deviation of fused image by using various fusion algorithms are from 6.9679 to 27.8102 (Table 1). Among them, the standard deviation of that of HPF fusion is the biggest, which indicate that the information in fused image was the richest. However, its texture structure is not very clear (Fig2a, Fig2e). This is because while enhancing the performance capabilities of spatial details of multi-spectral images by using HPF fusion it also increases the noise at the same time, which impacts the visual effects.
(a) Input Multispectral (MS) image.

(b) Input Panchromatic (PAN) image.

(c) Brovey fused image.

(d) Principal Component fused image.

(e) HPF fused image.

(f) HPF fused image.

Figure 2. (a) Input MS image. (b) Input PAN image. (c) Brovey fused image. (d) Principal Component fused image. (e) HPF fused image. (f) MT fused image.

Table 1: EVALUATION INDEX OF IMAGE FUSIONS

<table>
<thead>
<tr>
<th>Fusion Algorithm</th>
<th>Spectral Information Correlation Coefficient</th>
<th>Spatial Information Standard Deviation</th>
<th>Entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brovey</td>
<td>0.5200</td>
<td>62.6215</td>
<td>10.3435</td>
</tr>
<tr>
<td>HPF</td>
<td>0.3398</td>
<td>41.0418</td>
<td>27.8102</td>
</tr>
<tr>
<td>MLT</td>
<td>0.6376</td>
<td>48.6398</td>
<td>6.9679</td>
</tr>
<tr>
<td>PCA</td>
<td>0.5096</td>
<td>56.5499</td>
<td>9.8039</td>
</tr>
</tbody>
</table>

5. CONCLUSION

In this work, a new image fusion method is introduced. The fusion outcome is regarded as a linear combination of the input panchromatic and multispectral images. Tests with images collected by different sensors reveal that the proposed method is satisfactory. The HPF fusion method presents the best...
result for both visual and quantitative evaluations. This can be explained by the improvement of the spatial resolution and preservation of the spectral information. Moreover, the HPF method maintains the good spatial content to give an output. The spatial and spectral changes help in comparative study of various fusion techniques. It has been proved that PCA fusion technique preserves more spectral information as compared with Multiplicative and Brovey Image fusion techniques. The Multiplicative fusion technique preserves more spatial information as compared with PCA and Brovey image fusion techniques. Apart from this, the HPF yielded better results when compared with the PCA, BT and MT image fusion techniques.

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