Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

COMPARISON OF CONVENTIONAL AND WAVELET TRANSFORM TECHNIQUES FOR FUSION OF *IRS-1C LISS-III* AND *PAN* IMAGES

S. Sanjeevi*, K. Vani** and K. Lakshmi**
*Centre for Geoscience and Engineering, Anna University, Madras-600 025, INDIA
Email: ssanjeevi@annauniv.edu
**Institute of Remote Sensing, Anna University, Madras-600 025, INDIA
Email:vani@annauniv.edu

KEY WORDS: Multi-sensor image fusion, wavelet transform, image correlation, signature separability.

ABSTRACT: Image fusion is a technique of obtaining high spatial resolution multispectral images from low spatial resolution multispectral and high spatial resolution panchromatic images. Various techniques exist to perform such fusion. These techniques, however, do not seem to preserve the spectral information content of original multispectral image in the fused image. Hence, in this study a recent and efficient technique of fusion based on wavelet transformation was attempted and its efficiency was compared with that of the conventional techniques. Accordingly, a lower resolution multispectral image (IRS-1C LISS-III) and a high resolution panchromatic (IRS-1C PAN) were fused using three conventional techniques: IHS (Intensity Hue and Saturation), PCA (Principal Component Analysis) and Brovey Transformation and the recently evolved wavelet transformation technique. The four outputs were evaluated using visual comparison, statistical correlation (using AOI and image to image correlation) and spectral separability studies. Among the conventional methods, PCA based fusion was found to be better than IHS and Brovey transformation techniques in improving visual interpretability and in preserving the original spectral information content. When compared with conventional techniques, the wavelet transformation technique proved to be a better option since it preserved most (85%) of the spectral information content and also improved visual appreciation. Spectral separability between five land cover classes was also highest for the wavelet transformation technique. It is believed that, since wavelet transformation operates in the frequency domain, it is able to preserve most of the original image content in a better fashion than the conventional techniques, which operate in the spatial domain. Hence, it is suggested that image fusion be attempted in the frequency domain.

1.0 INTRODUCTION

Fusion produces a single (hybrid) image from a set of input images and helps us to extract maximum information from the data set in such a way as to achieve optimal spatial and spectral resolution. Wald (1999) describes fusion as "*a formal frame work in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of greater quality will depend upon application.*"

This work is an attempt to study the quality of the images fused by various conventional techniques and the recently evolved wavelet transformation techniques to ascertain the best possible technique that can result in better results of multi- sensor image fusion. Here, fusion of low-resolution multi-spectral data (IRS 1C LISS III; 23.5m resolution.) and a high resolution panchromatic data (IRS PAN; 5.8m resolution.) was attempted using certain conventional methods such as PCA, IHS, and Brovey transformation, and the results are presented. A recent technique, based on wavelet transformation, was also used for fusion and the results were evaluated and compared with the results of conventional fusion, especially in terms of preserving the spectral content of the multi spectral data.

This study assumes significance primarily due to the following reasons: (i) literature search indicates that fusion has been attempted only in Landsat TM, SPOT and SAR data while not much work has been reported regarding fusion of IRS LISS and PAN data; (ii) the advantage of fusing IRS LISS III and PAN is that both images belong to the same date and time, apart from having similar viewing geometry. Such a facility does not exist in fusing Landsat and SPOT or SAR and SPOT data, as they are obtained from different sensors and payloads; and (iii) to the knowledge of the authors, spectral separability of landcover classes as a basis of evaluating the quality of fused images, has not been reported in the available literature.

There are many methods available for image quality evaluation which include statistical comparison, visual comparison, graphical comparison, least mean square deviation computation and variance tabulation. Of these, the statistical comparison technique and visual comparison techniques have been used in this study. In addition, a new approach using spectral separability of landcover classes as a measure of the quality of fused images has also been attempted, besides evaluation of various approaches for image fusion.

Chavez *et al.* (1991) explain about IHS, PCA, HPF methods to merge multi-resolution and multi-spectral data: LANDSAT TM and SPOT Panchromatic and comparison of the methods. The authors observed that IHS method distorted the spectral characteristics of the data the most. In the PCA method, spectral distortion is less while the. HPF method distorts the data the least. Crawford *et al*.(1999), used fusion of airborne polarimetric and interferometric SAR for classification of coastal environments. The polarimetric sensor measures the radar back-scatter from the surface and vegetation, which can be used to infer structural properties of the surface and physical parameters, while data from interferometric sensor are used to determine the elevation of scatters within a resolution cell. Neural network and Bayesian pairwise classifiers in a multi-resolution framework was utilized and a good accurately classified map of the coastal test site was obtained. Li and Sheng (2000) describe about a fusion scheme based on "*a trous*" wavelet transformation for the fusion of IR and visible images. The author's report that the spatial resolution improvement of IR image was achieved and the salient detailed information from both visible and IR image were preserved Garguet-Duport *et al*.(1996) attempted merging using multi-resolution analysis based upon wavelet transform, for SPOT PAN and SPOT XS. This recent method is compared with the IHS method and P+XS method using three criteria: geometrical improvement, preservation of spectral characteristics and thematic analysis. The new method is found to be better because of minimal distortion of spectral characteristics. The authors also found this method very useful and particularly well adapted to vegetation analysis. As regards IRS data, Mohanty and Majumdar (1997) attempted IHS fusion using LISS III and PAN images. The authors observed moderate spatial distortion in the IHS fused image. From the above examples, it is observed that considerable work has been carried out with respect to image fusion techniques and applications. Also, it is seen that the wavelet transform method of image fusion is advantageous, compared to the older techniques and not much work has been reported about fusion of IRS data using wavelet techniques.

2.0 METHODOLOGY

2.1 Fusion of LISS-III and PAN images using conventional techniques.

Conventional methods adopted for image fusion include the PCA method, IHS method, Brovey transformation method and multiplicative method. Following is a brief explanation of these methods used in the present study. A detailed description can be found in Vani (1999), Pohl (1999) and Lakshmi (2000).

2.1.1 IHS method: This is a commonly used method wherein the three bands of the lower spatial resolution data are transformed to the IHS space. Intensity (I) refers to the total brightness of the colour, hue (H) to the dominant or average wavelength of the light contributing to the colour and saturation (S) to the purity of colour. The IHS transformation separates spatial (I) and spectral (H, S) information from a standard RGB image. The stretched higher spatial resolution image replaces the intensity component image and hue and saturation components are over-sampled to panchromatic resolution before the images are re-transformed back to the original space.

2.1.2 PCA method: The PCA method is much similar to the IHS method. The different bands of the multi-spectral image data are used as input to a principal component analysis procedure. All the spectral bands of the image are simplified into principal component axes. PCA removes the redundancy of information contents. Chavez et al. 1991 observe less spectral distortion in PCA method compared to IHS method because the principal component image is more correlated to PAN.

2.1.3 Brovey transformation method: This is a special arithmetic combination that includes ratios. It normalizes multi-spectral bands used for an RGB display and multiplies the result by any other higher resolution image to add the intensity or brightness components to the image. Pohl (1999) gives a detailed description of this technique.

Using the above mentioned three conventional techniques, fusion of the IRS LISS III and PAN images were attempted. The results are shown in Figure 1 c, d and e.

2.2 Fusion using wavelet transformation

The *wavelet transform* or *wavelet analysis* is probably the most recent solution to overcome the shortcomings of the Fourier transform. In the case of wavelets we normally do not speak about time-frequency representations but about time-scale representations, scale being in a way the opposite of frequency, because the term frequency is reserved for the Fourier transform. Figure 2 shows the various steps involved in fusion using wavelet transformation techniques. The first step in fusion using wavelet transformation consists in extracting the structures (also called "details") present between the images of two different resolutions. These structures are isolated into three wavelet coefficients, which

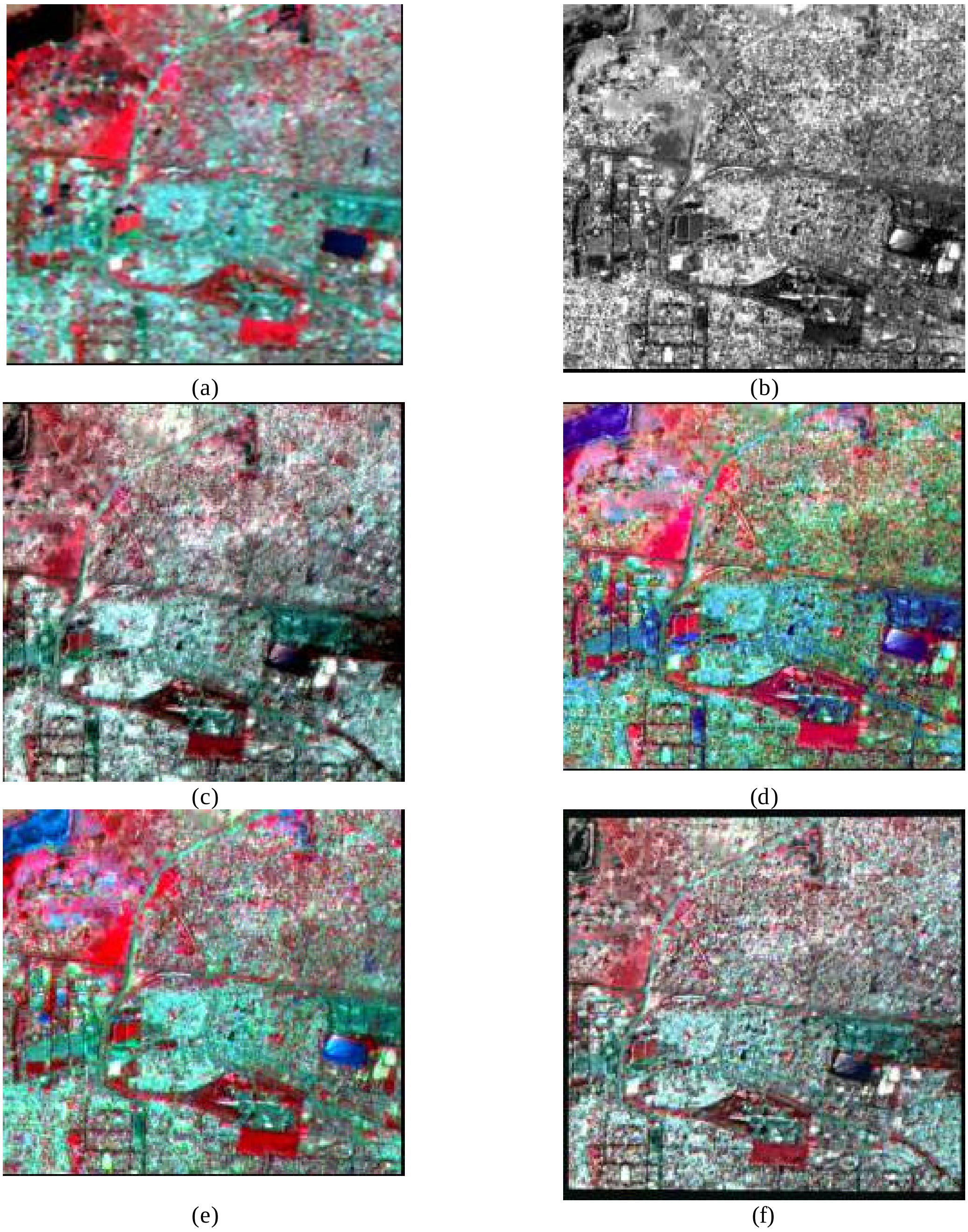

Figure 1. Input IRS images (a) LISS III (b) PAN and the resulting fused images : (c) PCA, (d) IHS, (e) Brovey and (f) Wavelet transform.

correspond to the detailed images according to the three directions (vertical, horizontal, and diagonal). Thus, in combining the high resolution panchromatic image and low resolution multi- spectral image, the PAN image is first reference stretched three times, each time to match one of multi-spectral band histograms. The first level of the wavelet transform is computed for each of these modified pan images. A synthetic level 1 multi-spectral wavelet decomposition is constructed using each original multi-spectral image and the three high frequency components from the corresponding modified PAN image. In the wavelet decomposition, four components are calculated from different possible combinations of row and column filtering (Figure 2). These components have low resolution because of down-sampling in wavelet transform. The second step introduces these details into each multi-spectral band through the inverse wavelet transform. Thus at high resolution, simulated images are produced. The spectral information content of original multi-spectral images is preserved because only the scale structures between the two different resolution images are added. Using the steps mentioned above, a fused image (Figure 1 f) was obtained.

3.0 EVALUATION OF RESULTS OF CONVENTIONAL AND WAVELET TECHNIQUES

As mentioned earlier, the conventional techniques of image fusion which include IHS, PCA and Brovey transform techniques were used to fuse the 23.5 m resolution LISS III multi-spectral image data and the 5.8 m resolution panchromatic image data (also see table-1). Each technique resulted in fused images with varied characters.

Visual comparison suggests that the fused image had improved spatial resolution compared to the original LISS-III image. Amongst the conventional techniques, it was observed that the PCA seems to give the best results of fusion. Wavelet fused image has a "better look " compared to the original LISS III FCC (see Fig 1 a, b and f). Almost all the features (urban, vegetation and water) are very well presented and the colour scheme is also as good as the original LISS III image. Thus with a visual estimate, the result of the wavelet transform method seems to be the best among all the fusion methods. As already mentioned, due to limitations of human vision in terms of distinguishing the number of grey levels, comparison and appreciation by visual methods does not reveal the exact potentials of the fusion methods. Hence, comparison of image statistics was attempted to evaluate the results of fusion using PCA and wavelet transform methods. It is believed that such a comparison would accurately quantify the loss of spectral information after fusion.

Image statistics were generated using two approaches: the AOI approach and the image-to-image correlation approach. Table 1 shows the values of correlation coefficient computed for various methods of merging. It is evident from the table that PCA method of image fusion results in the best possible correlation between the original, multi-spectral LISS III and the fused (multi-spectral) image (r for b1=0.51, r for b2=0.69, r for b3=0.59). The next higher coefficient of correlation is for the Brovey transform method (r for b1=0.71, r for b2=0.65, r for b3=0.24) which is followed by the IHS method (r for b1=0.57, r for b2=0.19, r for b3=0.45).

Table 1. Correlation between LISS III and Fused outputs

Technique	AOI	Image to Image Correlation			
		LISS III Band 1	LISS III Band 2	LISS III Band 3	LISS III Band 4
IHS	0.59	0.57	0.19	0.45	0.42
Brovey	0.60	0.71	0.65	0.24	0.45
PCA	0.70	0.51	0.69	0.58	0.59
Wavelet	0.87	0.86	0.85	0.83	0.85

A cursory review of Table 1 reveals that the correlation between the original LISS III image data and the fused image is highest for the wavelet transform method. This is followed in succession by PCA, Brovey transform and IHS method.

It is opined that the correlation coefficient directly indicates the amount of spectral content preserved. High values of correlation, of the order of r = 0.86 for band1, r = 0.85 for band2, r = 0.83 for band3, for the wavelet are indicative of the fact that on an average 85% of the spectral content of the LISS III image seems to be preserved in the fused image. In other words, about 15% spectral content is lost on fusion using wavelet transform method. In a similar fashion, about 62.5% of information is preserved in the fused image when PCA technique is used. Brovey transform results in only 53% of spectral content being preserved in fusion while only 43% of the spectral content is preserved in the IHS technique. An explanation for PCA being better than Brovey and IHS transform; and Brovey transform being better than IHS transform is as follows : in the PCA method, the first principal component is replaced by PAN and in IHS the intensity component is being replaced by PAN. In PCA the assumption is that the first principal component is approximately equivalent to PAN and in IHS the assumption is that the intensity component is approximately equivalent to PAN. But the first assumption is more nearer to the fact, compared to the latter one. Hence a better output is obtained in PCA method compared to IHS method. The highest preservation of spectral content using the wavelet transform is revealed by the good exhibition of urban, vegetation, and water bodies.

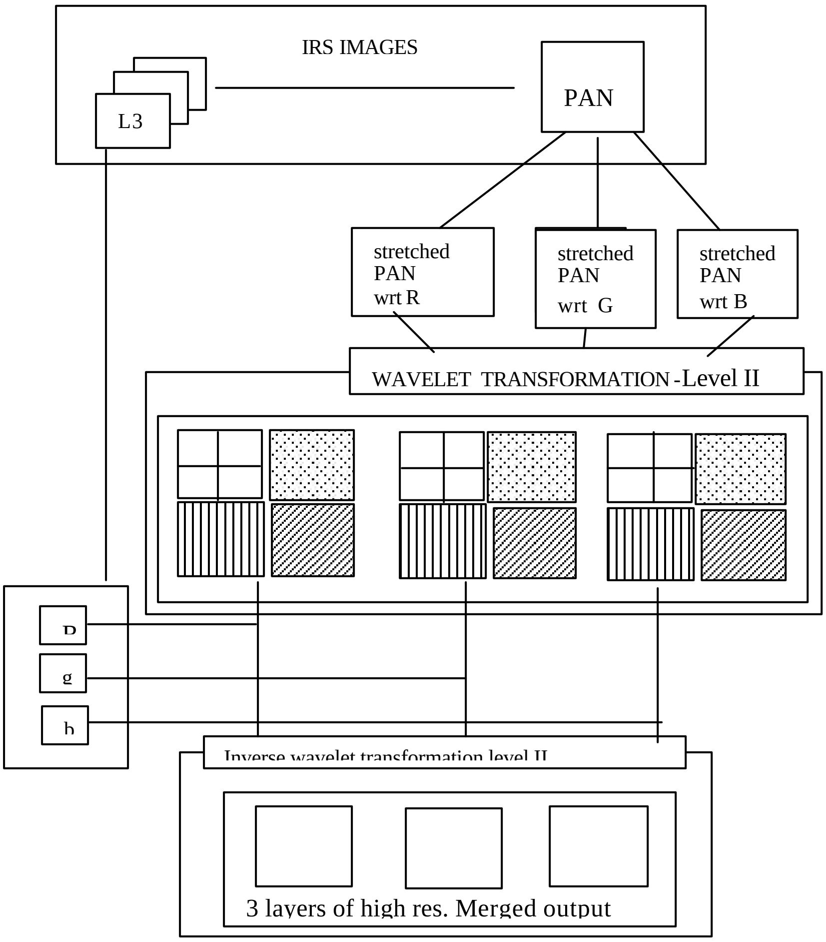

Figure.2 Principles of wavelet merging method

Apart from image to image correlation and AOI to AOI correlation, it is believed that the spectral separability between landcover classes could be a better estimate of the quality of fused image. There are many measures available to express the degree of separability between spectral classes. A few of these are the Euclidean distance, divergence, Jefferies-Matusita distance and Transformed Divergence. As is well known, the better separability of training class signatures results in accurate thematic maps. It is also a valuable tool to measure the performance of fusion techniques.

Of the various measures, only the Euclidean distance and Transformed Divergence have been used in this study because of their efficiency, ease of computation and comparison. *Euclidean distance* refers to the distance between means of the spectral classes. Though this measure does not give the accurate estimate of class separability due to the influence of the standard deviations of the class distribution on the overlap of the classes, it gives us a broad idea of the separability between the classes. However, Euclidean distance alone cannot be used as an estimator of separability between classes and the use of other measures is essential. *Transformed Divergence* (TD) is calculated from the means and covariance matrices of each training class, it is a measure of the statistical distance between training group pairs of interest and provides information on their separability. Swain and Davis 1978, explain in detail the concept of TD and its significance. It can be considered as an *apriori* estimate of the likelihood of correct classification between groups of different feature combinations.

Table 2. Average separability in DN between the landcover classes present in the study area.

Separability	Veg1	Veg2	Wat1	Wat2	Set1	Set2	Set3
ED - PCA	145	147	178	173	215	204	148
ED - WL	157	157	193	187	227	229	157
TD - PCA	1588	1445	1714	1714	1714	1609	1609
TD - WL	1710	1710	1714	1714	1714	1676	1714

Note: ED=Euclidean Distance; TD=Transformed Divergence; PCA=Principal Component Analysis; WL=Wavelet Transformation; Veg=Vegetation; Wat=Water; Set=Settlement.

Table 2 shows the average separability between landcover classes in the PCA and wavelet fused images. The Euclidean distance (ED) and Transformed Divergence (TD) measures have been used to describe the separability of classes. It is readily evident from Table 2 that fusion using wavelet transformation results in highest overall separability followed by fusion by PCA. The original LISS III images present the least separability for all the classes.

It may also be inferred from Table 2 that the Euclidean distance is higher for all classes when fusion is performed with wavelet transformation technique, while it is lower when PCA is adopted for fusion. Similarly, Transformed Divergence measure yields average values which are higher for the fused image resulting from wavelet transformation. The separability measures such as the Euclidean Distance and the Transformed Divergence values have thus provided us with the opportunity to examine the quality of the training sites and the class signatures. A comparison of the class signatures reveals that the urban classes have the highest separability. Fused images obtained with the wavelet fusion technique possess higher separability of urban classes compared to the PCA fused image. Similar observations have also been reported by Wald, 1997 and Pohl, 1999. Water bodies have the next higher separability values with highest value being shown in the wavelet fused image, followed by the PCA fused image. Vegetation has the least inter-class separability. Fusion, however, has increased the separability of vegetation features. This increase is the highest in the wavelet transform fused image, followed by the PCA fused image. This is in agreement with the findings of Garguet-Duport *et al*.(1996), who also state that vegetation features are enhanced in images fused using wavelet transformation.

4.0 CONCLUSION

This paper has demonstrated the potentials of fusion as a tool for improving the interpretability of low resolution images. Among the three conventional techniques PCA is found to be best method followed by Brovey and IHS in terms of preserving the spectral characteristics as well as for visualisation . The wavelet technique is found to give an output which is "better looking" and it also preserves the spectral content (up to 85%) of LISS III data in a better fashion. This is evidenced by the highest co-efficient of correlation for the image fused with wavelet technique. Signature separability as a quantitative indicator of the quality of the fusion tool has been successfully demonstrated here. Experimental results show that wavelet transformation technique may be used as an efficient image fusion tool.

REFERENCES

Chavez, P. S. Sides, S. C. and Anderson, J. A. 1991. Comparison of three different methods to merge multi resolution and multi-spectral data: Landsat TM and SPOT panchromatic. Ph. Engg. and Rem. Sen. 57 (3) pp. 295-303.

Crawford, M. M, Kumar, S., Richard, M. R., Giberaut, J. C and Schwander, A. N. 1999. Fusion of airborne polarimetric and interferometric SAR for classification of coastal environments. IEEE Tran. Geosci.& Engg. 39 (3). pp. 1306-1315.

Garguet-Duport, B., Jacky Girel, Jean Mark Chassery and Patou. 1996. The use of multi-resolution analysis and wavelet transform for merging SPOT Panchromatic and multi-spectral image data. Ph. Engg. & Rem.Sen.62 (9). pp1057 -1066.

Lakshmi, K., 2000. Improved information extraction using image fusion techniques. M.Tech Thesis. Anna University.

Li. L, and Sheng, Y., 2000. Improving spatial resolution of IR images by means of sensor fusion. URL: *http://www.tropin.phy.ulaval.ca/jli.*

Mohanty K. K and Majumdar, T. J., 1997. A comparison of IRS-1C, Panchromatic and LISS III data fusion using adaptive filtering, IHS and fourier transform. In ISRS and NNRMS Bulletin.(Rem. Sen. for Nat. Res.). pp 420-429.

Pohl, C. 1999. Tools and methods for fusion of images of different spatial resolution. International Archives of Photogrammetry and Remote Sensing. 32 (7-4-3). Valladolid. Spain.

Vani, K. 1999. Merging and Analysis of multi-resolution satellite images. Unpublished M.E Thesis, Anna University.

Wald, L., 1999. Definitions and terms of references in data fusion. International Archives of Photogrammetry and Remote Sensing. 32 (7-4-3) Valladolid. Spain.

Wald, L., Ranchin, T., and Mangolini. M. 1997. Fusion of Satellite images of different spatial resolutions: Assessing the quality of resulting images. Ph. Engg. and Rem. Sen. 63 (6). pp. 691-699.