QUALITY ASSESSMENT OF IMAGE FUSION TECHNIQUES FOR MULTISENSOR HIGH RESOLUTION SATELLITE IMAGES (CASE STUDY: IRS-P5 AND IRS-P6 SATELLITE IMAGES)

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ABSTRACT:

This paper is concentrated on the evaluation of the image fusion techniques applied on the IRS P5 and P6 satellite images. The study area is chosen to cover different terrain morphologies. A good fusion scheme should preserve the spectral characteristics of the source multi-spectral image as well as the high spatial resolution characteristics of the source panchromatic image. In order to find out the fusion algorithm which is best suited for the P5 and P6 images, five fusion algorithms, such as Standard IHS, Modified IHS, PCA, Brovey and wavelet algorithms have been employed and analyzed. In this paper, eight evaluation criteria are also used for quantitative assessment of the fusion performance. The spectral quality of fused images is evaluated by the Spectral discrepancy, Correlation Coefficient (CC), RMSE and Mean Per Pixel Deviation (MPPD). For the spatial quality assessment, the Entropy, Edge detection, High pass filtering and Average Gradient (AG) are applied and the results are analyzed. The analysis indicates that the Modified IHS fusion scheme has the best definition as well as spectral fidelity, and has better performance with regard to the high textural information absorption. Therefore, as the study area is concerned, it is most suited for the IRS-P5 and P6 image fusion.

1. INTRODUCTION

Due to physical constraint, there is a trade off between spatial resolution and spectral resolution of a high resolution satellite sensor (Aiazzi et al., 2002), i.e., the panchromatic image has a high spatial resolution at the cost of low spectral resolution, and the multispectral image has high spectral resolution with a low spatial resolution (IKONOS: panchromatic image, 1m, multispectral image 4m; QuickBird: panchromatic image, 0.62m, multispectral image, 2.48m). To resolve this dilemma, the fusion of multispectral and panchromatic images, with complementary spectral and spatial characteristics, is becoming a promising technique to obtain images with high spatial and spectral resolution simultaneously (Gonzalez-Audicana et al., 2004). Image fusion is widely used to integrate these types of data for full exploitation of these data, because fused images may provide increased interpretation capabilities and more reliable results since data with different characteristics are combined. The images varying in spectral, spatial and temporal resolution may give a more comprehensive view of the observed objects (Pohl and Genderen, 1998).

2. IMAGE FUSION ALGORITHMS

Many methods have been developed in the last few years producing good quality merged images. The existing image fusion techniques can be grouped into four classes: (1) color related techniques such as intensity–hue–saturation (IHS) ; (2) statistical/numerical methods such as principal components analysis (PCA), high pass filtering (HPF), Brovey transform (BT), regression variable substitution (RVS) methods; (3) Pyramid based Methods such as Laplacian Pyramid, Contrast Pyramid, Gradient Pyramid, Morphological Pyramid and Wavelet Methods and (4) hybrid methods that use combined methods from more than one group such as IHS and wavelet integrated method. This study analyzes five current image fusion techniques to assess their performance. The five image fusion methods used include Standard IHS, Modified IHS, PCA, Brovey and wavelet algorithms.

IHS (Intensity-Hue-Saturation) is the most common image fusion technique for remote sensing applications and is used in commercial pan-sharpening software. This technique converts a color image from RGB space to the IHS color space. Here the I (intensity) band is replaced by the panchromatic image. Before fusing the images, the multispectral and the panchromatic image are histogram matched.

Ideally the fused image would have a higher resolution and sharper edges than the original color image without additional changes to the spectral data. However, because the panchromatic image was not created from the same wavelengths of light as the RGB image, this technique produces a fused image with some color distortion from the original multispectral (Choi et al., 2008). There have been various modifications to the IHS method in an attempt to fix this problem (Choi et al., 2008; Strait et al., 2008; Tu et al., 2004; Siddiqui, 2003). In this research is used modification method suggested by Siddiqui (2003).

The Principal Component Analysis (PCA) is a statistical technique that transforms a multivariate dataset of correlated variables into a dataset of new uncorrelated linear combinations of the original variables (Pohl and Genderen, 1998). It is assumed that the first PC image with the highest variance contains the most amount of information from the original image and will be the ideal choice to replace the high spatial resolution panchromatic image. All the other multispectral bands are unaltered. An inverse PCA transform is performed on the modified panchromatic and multispectral images to obtain a high-resolution pan-sharpened image.

Brovey Transform uses addition, division and multiplication for the fusion of three multispectral bands (ERDAS, 1999). Its basic processing steps are: (1) add three multispectral bands together for a sum image, (2) divide each multispectral band by the sum image, (3) multiply each quotient by a high resolution pan.

In wavelet fusion method First, three new panchromatic images are produced according to the histogram of R, G, B bands of multispectral image respectively. Then 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 (B,G,R), 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,R). After three times of 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 (Zhang, 2005).

3. QUALITY ASSESSMENT CRITERIA

Quality refers to both the spatial and spectral quality of images (Wald, 1997). 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 (Xu, 2004). In this paper, eight 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 and Mean Per Pixel Deviation (MPPD). For the spatial quality assessment, the Entropy, Edge detection, High pass filtering and Average Gradient (AG) are applied and the results are analyzed.

3.1 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 inflect the spectral fidelity of fusion image include:

3.1.1 Correlation Coefficient: 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 (Han et al.,2008). The ideal value of correlation coefficient is 1.

$$CC(A,B)=\frac{\sum_{mn}(A_{mn}-\bar{A})(B_{mn}-\bar{B})}{\sqrt{(\sum_{mn}(A_{mn}-\bar{A})^2)(\sum_{mn}(B_{mn}-\bar{B})^2)}} \quad (1)$$

where $\bar{A}$ and $\bar{B}$ stand for the mean values of the corresponding data set, and CC is calculated globally for the entire image.

3.1.2 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:

$$\begin{aligned} RMSE &= \sqrt{bias^2+\sigma^2} \\ \sigma &= \sigma_{org}+\sigma_{fused} \\ bias &= \bar{x}_{org}-\bar{x}_{fused} \end{aligned} \quad (2)$$

In this formula s is standard deviation, x is Mean, org is Original image and fused is Fused image.

3.1.3 Mean Per Pixel Deviation: For this method it is necessary to degrade the fused image to the spatial resolution of the original image. This image is then subtracted from the original image on a per pixel basis. As final step, we calculated the average deviation per pixel measured as digital number which is based on an 8-bit or 16-bit range, depending on the radiometric resolution of the employed images (Wald, 2002; Ehlers et al., 2008).

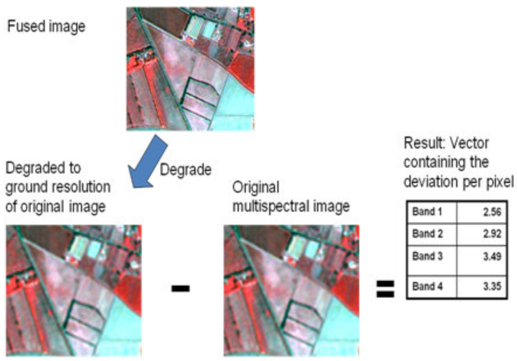


Figure 1. Calculation of Mean Per Pixel Deviation

3.1.4 Spectral discrepancy: The spectral quality of a $P\times Q$ fused image can be measured by the discrepancy D_k at each band (Li et al., 2005):

$$D_k=\frac{1}{P.Q}\sum_{x=1}^{P}\sum_{y=1}^{Q}\left|F_k(x,y)-L_k(x,y)\right|, k=R,G,B \quad (3)$$

where $F_k(x,y)$ and $L_k(x,y)$ are the pixel values of the fused and original mutispectral images at position (x,y), respectively.

3.2 Spatial Quaqlity 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:

3.2.1 High Pass Filtering: For the spatial quality, we compare the high frequency data from the panchromatic image to the high frequency data from each band of the fused image using a method proposed by Zhou in 2004. To extract the high frequency data we apply the following convolution mask to the images:

$$mask = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \qquad (4)$$

The correlation coefficients between the high-pass filtered fusion results and the high-pass filtered panchromatic image is used as an index of the spatial quality (Hong, 2007). The principle is that the spatial information unique in panchromatic image is mostly concentrated in the high frequency domain. The higher correlation between the high frequency components of fusion result and the high frequency component of panchromatic image indicates that more spatial information from panchromatic image has been injected into the fusion result.

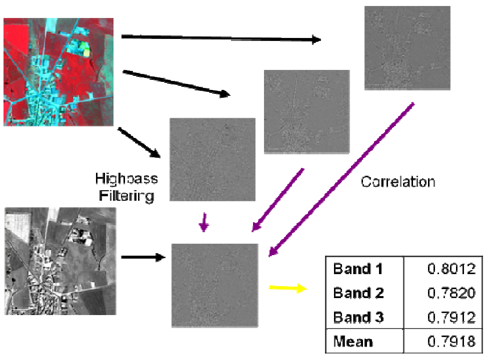


Figure 2. Spatial quality assessment by high pass filtering

3.2.2 Edge detection: In this method first detect the edges of panchromatic and fused image by canny operator. the more closely the edge data of the fused image matches the edge data of the panchromatic, indicating better spatial quality.

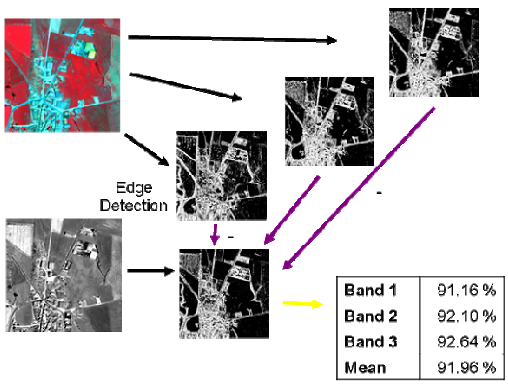


Figure 3. Spatial quality assessment by edge detection

3.2.3 Average gradient: For the spatial quality, we use the average gradient to evaluate the performance of the fused image F. That is

$$ag_k = \frac{1}{(P-1)(Q-1)} \times \sum_{x=1}^{P-1} \sum_{y=1}^{Q-1} \sqrt{\frac{(\frac{\partial F_k(x,y)}{\partial x})^2 + (\frac{\partial F_k(x,y)}{\partial y})^2}{2}}$$

$$k = R, G, B \qquad (5)$$

where $F_k(x,y)$ is the pixel value of the fused image at position (x,y). The average gradient reflects the clarity of the fused image. It can be used to measure the spatial resolution of the fused image, i.e., a larger average gradient means a higher spatial resolution (Li et al., 2005).

3.2.4 Entropy: Entropy as a measure to directly conclude the performance of image fusion. The Entropy can show the average information included in the image and reflect the detail information of the fused image (Han et al.,2008). 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:

$$E = -\sum_{i=0}^{255} P_i \log_2 P_i \qquad (6)$$

Where E is the Entropy of image, and P_i is the probability of i in the image.

4. EXPERIMENT DATA AND ANALYSIS OF FUSION RESULTS

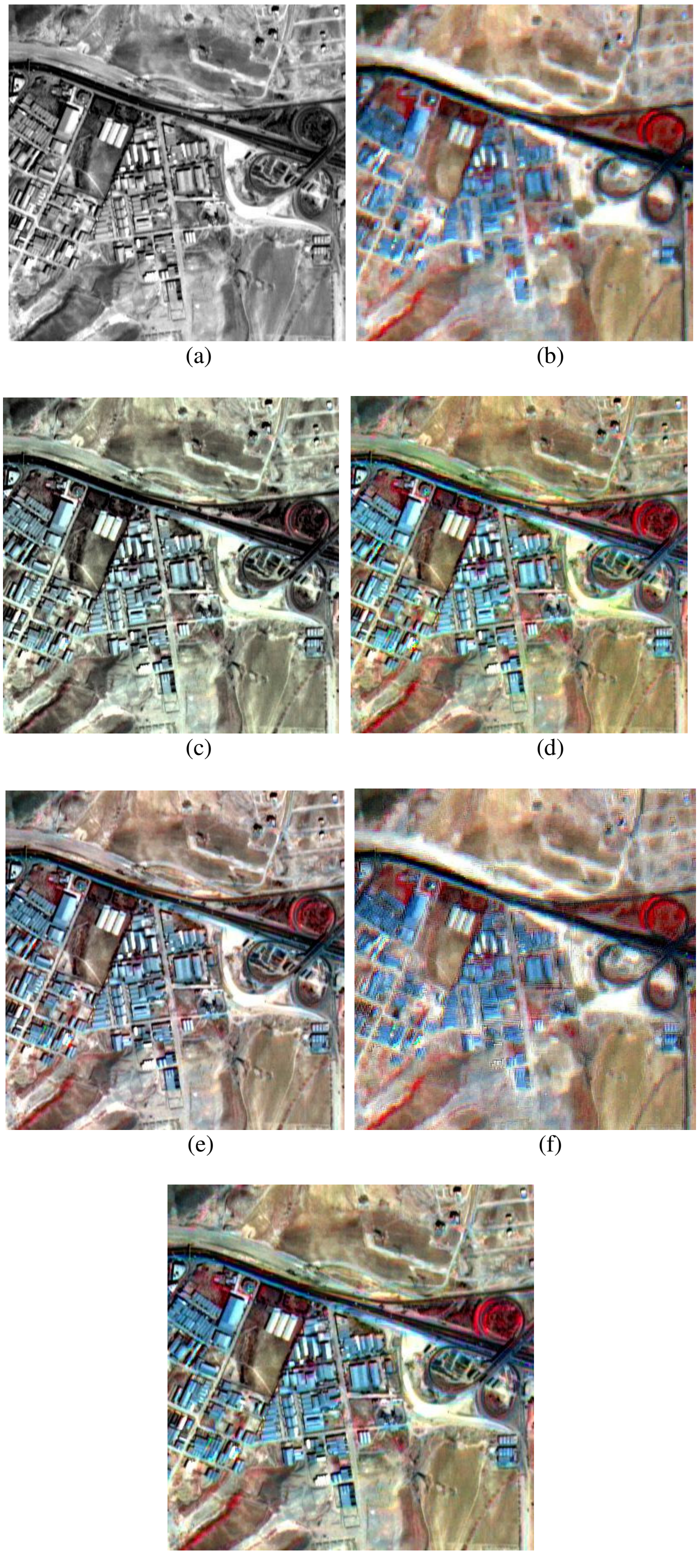
4.1 Experiment Data

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. The study area is chosen to cover different terrain morphologies. Figure 4 shows an example of the fused IRS-P6 MS and IRS-P5 pan images using five fusion algorithms, such as Standard IHS, Modified IHS, PCA, Brovey and wavelet algorithms.

4.2 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.

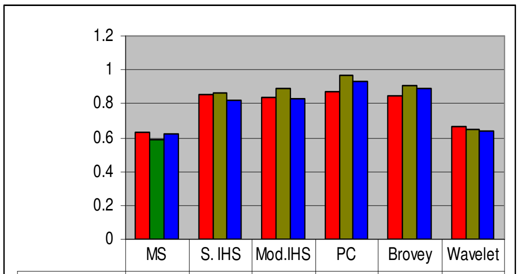
4.2.1 Spatial Quality Assessment: Figure 5 shows the correlation coefficients between high pass filtered results and high pass filtered panchromatic image, PC is the highest, Standard IHS is the second and wavelet is the lowest. That means the PC and Standard IHS fusion results are injected into the most spatial information, while the wavelet fusion result is injected into the least spatial information.
The average gradients of the images obtained by different fusion algorithms are shown in figure 6. The ag of Standard IHS is the highest in the five algorithms, and ag of PC and Modified IHS is the further maximum. therefore, the Standard IHS-fused image has absorbed the high spatial frequency information most and thus shows sharper than the others.



(g)

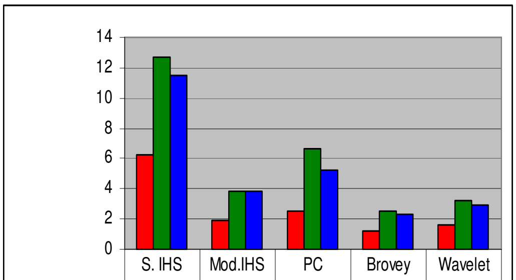
Figure 4. (a) original Pan image. (b) original MS image. (c) Standard IHS fused image. (d) modified IHS fused image. (e) PC fused image. (f)Wavelet fused image. (g)Brovey fused imge.

Figure 7 shows the Entropy of each band MS and fused images. The Entropy of Standard IHS is the highest in the five algorithms. The Entropy can reflect the average information included in the fused image, therefore, the Standard IHS-fused image has absorbed the high spatial frequency information most and thus shows crisper than the others. Entropy of PC is the further maximum and Entropy of Brovey is minimum.
figure 8 shows the wavelet fusion result has the lowest of edge accordance whit panchromatic image in the five algorithms, that indicating worse spatial quality.



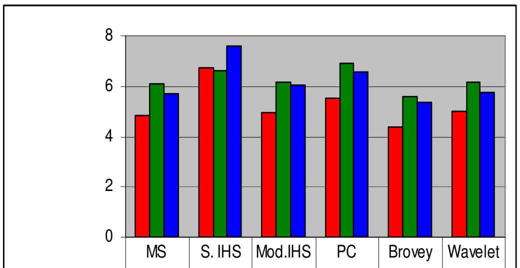
	MS	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	0.633	0.855	0.836	0.876	0.848	0.665
Band G(R)	0.59	0.859	0.885	0.965	0.903	0.65
Band B(G)	0.62	0.816	0.832	0.936	0.888	0.642

Figure 5. Correlation coefficients between the high pass filtered panchromatic image and high pass filtered fusion results.



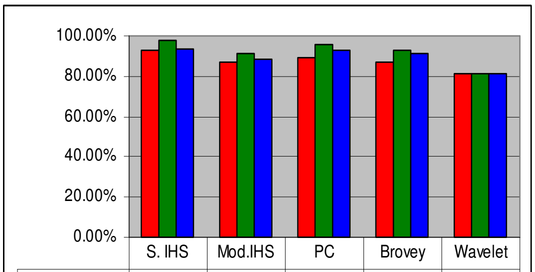
	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	6.257	1.924	2.518	1.222	1.62
Band G(R)	12.684	3.862	6.667	2.47	3.191
Band B(G)	11.434	3.861	5.198	2.304	2.952

Figure 6. Average gradients of the fused images.



	MS	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	4.861	6.732	4.922	5.528	4.399	5.034
Band G(R)	6.114	6.59	6.165	6.912	5.558	6.14
Band B(G)	5.714	7.589	6.044	6.553	5.342	5.759

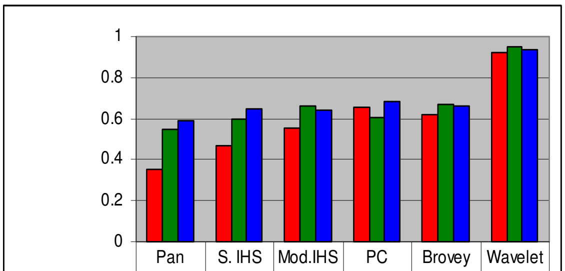
Figure 7. Entropy of the MS and fused images.



	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	92.71%	87.24%	88.91%	87.05%	81.03%
Band G(R)	98.00%	91.12%	95.87%	92.59%	81.43%
Band B(G)	93.83%	88.83%	93.09%	91.49%	81.49%

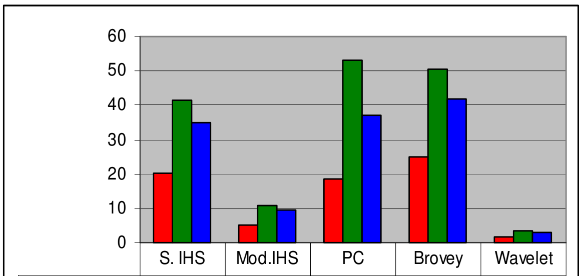
Figure 8. edge accordance of fused images whit panchromatic image

4.2.2 Spectral Quality Assessment: In Figure 9, the original panchromatic image has a low correlation with the original multispectral image. The correlation between the fusion result and multispectral image are much greater than the correlation between the panchromatic
image and multispectral image. The highest correlation coefficient is wavelet, therefore According to this quantitative analysis, wavelet is the best that means preserve the spectral characteristics of the source multi-spectral image.
figure 10 shows the spectral discrepancies between the images obtained by different fusion algorithms and the source multispectral image. It clearly indicates that the discrepancy of wavelet is the minimum, and discrepancies of Modified IHS is the further minimum. So wavelet is the best method in retaining spectral property of the original image among the five used methods and Modified IHS takes second place.
Figure 11 shows the RMSE of MS and fused images. It clearly indicates that the RMSE of wavelet is the minimum, and RMSE of Modified IHS is the second minimum.
Figure 12 shows that The MPPD of PC-fused image is the highest in the five algorithms. wavelet is the minimum.
According to the RMSE and MPPD, we can see that the wavelet-fused image has the maximal relativity with MS image. So wavelet is the best method in retaining spectral property of the original image among the five used methods, and Modified IHS takes second place.



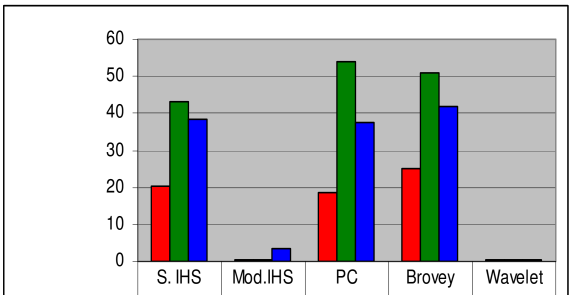
	Pan	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	0.354	0.468	0.551	0.657	0.616	0.919
Band G(R)	0.55	0.598	0.665	0.605	0.672	0.951
Band B(G)	0.593	0.649	0.637	0.682	0.665	0.933

Figure 9. Correlation coefficient between the original multispectral image and fusion results



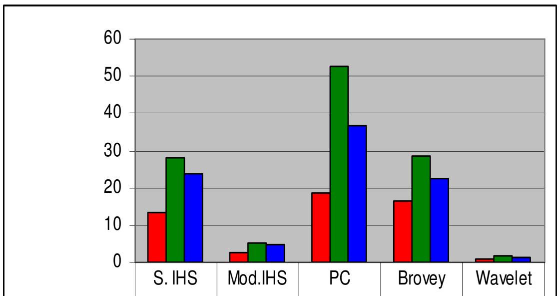
	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	20.192	5.337	18.479	24.83	1.835
Band G(R)	41.422	10.579	53.245	50.523	3.661
Band B(G)	34.867	9.294	36.941	41.887	3.124

Figure 10. Spectral discrepancies between the the original multispectral image and fusion results



	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	20.181	0.609	18.521	24.996	0.326
Band G(R)	43.255	0.385	53.873	50.888	0.392
Band B(G)	38.407	3.329	37.726	42.018	0.308

Figure 11. RMSE between the the original multispectral image and fusion results



	S. IHS	Mod.IHS	PC	Brovey	Wavelet
Band R(NIR)	13.232	2.517	18.354	16.342	0.829
Band G(R)	28.068	5.098	52.766	28.654	1.643
Band B(G)	23.678	4.664	36.705	22.422	1.41

Figure 12. MPPD of the fused images.

5. CONCLUSIONS

Finally, from the above analysis and comparison, we can conclude that Modified IHS algorithm can preserve the spectral characteristics of the source multispectral image as well as the high spatial resolution characteristics of the source panchromatic image and suited for fusion of IRS P5 and P6 images.
In PC and Standard IHS image fusion, dominant spatial information and weak colour information is an often problem, Therefore are suited for visual interpretation, image mapping, and photogrammetric purposes.

wavelet is the best method in retaining spectral property of the original image among the five used methods at the cost of low spatial information, Therefore are suited for digital classification purposes.

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