Comparison of Performance of Various Image Fusion Techniques using IKONOS-2 Data

Megha K. Mehta, Nehal G. Chitaliya, Paru Thakkar, Madhukar B. Potdar

***Abstract*— Image fusion or spectral merging techniques combine low spatial resolution multispectral data with high spatial resolution PAN data to extract maximum advantage in terms of both spatial and spectral resolutions. Many methods have been suggested in literature for image fusion depending on color and fusion models. In this paper, the process of Image fusion/pan-sharpening following 10 approaches based on different color models and spatial transformations have been compared using IKONOS-2 pan and multispectral data. Also, a concept of controlled injection of intensity component is introduced to study its impact on the variation of spectral correlation. The performances of various methods are evaluated through various statistical parameters.**

***Index Terms*— Color Models, Image Fusion, Spectral Merging, PAN-sharpening, IKONOS.**

I. INTRODUCTION

Remote sensing instruments' data are characterized by properties like spatial, spectral, temporal and radiometric resolutions. Panchromatic (PAN) data have high spatial resolution as well as high radiometric resolution, whereas the multispectral (MS) data have low spatial resolution and high spectral resolution due to constrain on signal-to-noise ratio of radiometry [2]. The technique of spectral merging or image fusion was introduced for gain most from the two types of data; albeit one at the cost of the other. This technique aims at high spatial resolution data at high spectral resolution at low cost. But, it hampered by the disproportionate spectral coverage of PAN and MS sensors.

The PAN and MS data from commercial satellite sensors -such as IKONOS, OrbView, and QuickBird—are commonly used today in remote sensing applications [1] and high potential for fusion. This type of sensors gives MS image and PAN image. The aim of image fusion is technique also to get image with high spatial resolution and high spectral resolution for clear visibility. Clearly visible being individual trees, automobiles, road networks, and houses, the IKONOS images allow for a more accurate understanding of phenomena on the ground [5].

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There are various color models and fusion methods based on them. In this paper, the process of Image fusion/pan-sharpening following 10 approaches based on different color models have been applied on a sample of IKONOS-2 pan and multispectral data. The performances of various methods are evaluated through different statistical parameters of fusion mainly keeping in view the spectral and spatial correlations. Other methods such as Fast-IHS and Adaptive Component substitution are not considered in this paper.

II. FUSION TECHNIQUE

IHS is mostly commonly used for image fusion [3]. The red, green and blue primary colors are as axis in cubic, cylindrical, conic, spherical spaces, also hex-conic and bi-hex-conic spaces [3]. Based on these representations, different transformations to obtain intensity (I), hue (H) and saturation (S) components are discussed widely in literature and are summarized by [3]. These transformations work well when the three MS data represent the three primary colors in true spirit. But, in practice, situation is far from ideal due to technological constraints. Among the synchronously acquired PAN and MS data from a single platform, the IKONOS-2 data have fairly good spectral coverage and form test bed of color fusion methods.

As the pan data are acquired by a separate sensor, they have high radiometric range and accuracy compared to MS data. Higher spectral coverage at shorter blue wavelengths is usually limited to avoid the Rayleigh background. Because of different spectral coverage and variations in response functions, the Intensity component from IHS transformation does not radiometrically match well with the pan component Thus, the fusion results in to significant color distortion. It can be minimized by using histogram matching technique. The pan needs to be subjected to histogram matching before fusion.

III. DATA USED

The present investigation uses the IKONOS-2 satellite Multi-spectral and Pan data. IKONOS was launched on September 24, 1999, and provides imagery beginning January 1, 2000. IKONOS is used to study land use types. The IKONOS-2 satellite data have MS resolution of 4 m and PAN resolution of 1 m. Spectral range of blue band is 455-520 µm, green band is 510-600 µm, red band is 630-700 µm, NIR band is 760-850 µm and, PAN band is 760-850 µm. The swath coverage is 11 km x 11km. One scene data of size about 2750x2750 pixels of MS data were scaled by a factor of 4 to match to the size of 11000x11000 pixels of PAN image. The resultant images of both MS and PAN are then subset into multiple scenes of 512x512 pixels. Out of these, 5 subset were chosen such that they covered wide range of land use classes such as forest, wasteland, wetland, urban and Water body. The data were downloaded from the GLCF web site.

IV. METHODOLOGY

The methodology followed is shown in the flow chart (Fig. 1). Specifically, the Red, Green and, Blue components of MS data and pan data are spatial co-registered up zooming MS data to match pan spatial resolution, as the two sensors data are acquired synchronously from the same platform. All the data are brought to radiometric range by histogram stretching from 0 to 255 ranges. The IHS forward transformations given by [3] are applied to generate the Intensity (I), Hue (H) and, Saturation (S) components. The pan image is transformed to match its histogram with that if the intensity component. The Intensity component (I) is then replaced by the histogram matched pan image before applying the inverse transformation to generated fused red, green and blue components. These components are then histogram contracted to match those of the original MS images.

Due to the higher NIR coverage by pan sensor compared to the MS [4], the pan data show higher contrast of vegetation areas. Therefore, controlled fusion need to be applied. This is achieved by scaling histogram matched pan component by applying injection factor (k). These factors scales down the radiometry and thus contrast in the resultant image.

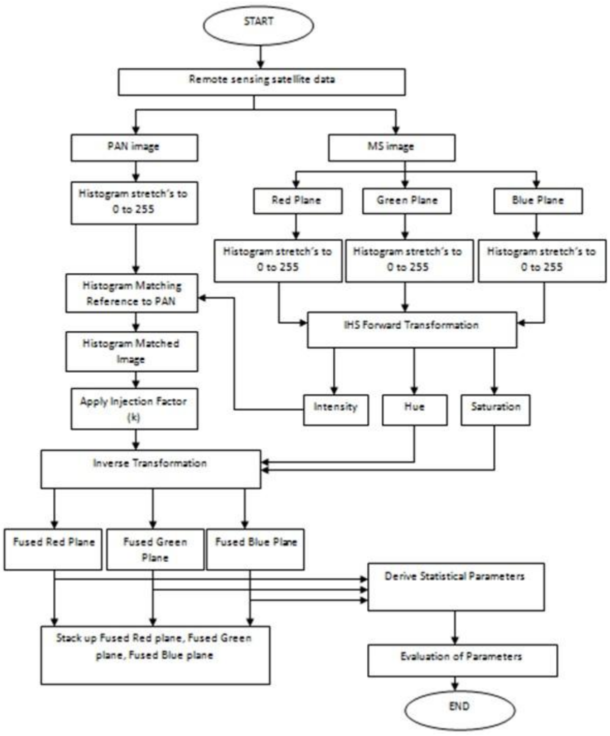

Fig.1 Image fusion process flow

The PC based method takes into account all the bands including NIR band. This method also followed and the results are compared with the other RGB based fusion methods. In this method all the four PCs are used to generate Intensity Image. Spectrally, this intensity component is matching well with the spectral coverage of PAN sensor, due to which the spectral distortion is expected to be minimum.

The quality of the fusion process is then evaluated through the statistical parameters like spectral Correlation Coefficients (CC), Mean and Standard Deviation (SD) or variance, Quality Index (Q), Image Difference Index (DI), Entropy, Normalized Root Mean Square Error (NRMSE) and Signal-to-Noise Ratio (SNR) etc. of both the original low spatial resolution and fused high resolution MS images. Definitions of the statistical parameters are taken from [3].

V.RESULTS AND DISCUSSION

Various fusion methods described in [3] are based on different color transformations and in some cases involve certain radiometric and spatial transformations. The methods have been named as HSV, ISH1, ISH2, ISH3, ISH4, ISH5, ISH6, ISH7, and HLS. Here H stands for Hue, S for Saturation, V for Value, and L for Luminance. In paper [3], the PAN data from the 5.8 m resolution Cartosat sensor on an Indian Remote Sensing Satellite and the MS from 30 m resolution Landsat TM sensor data. The drawback of using PAN and MS data from two different satellite platforms as well as of two different atmospheric conditions and viewing geometries need not emphasized here. Also, there are problems associated with spectral coverage and spectral response. There, we decided to use the PAN and MS data acquired synchronously and from a single satellite platform and having better spectral coverage, such as IKONOS data.

The IKONOS-2 data set is fused using different fusion algorithms described in [3,7,8,11]. Software simulation for image fusion has been done on MATLAB tool. Statistical parameters are also developed on MATLAB tool. Original PAN, original MS and Image fusion implemented with different fusion methods considering the histogram matched PAN data with the Intensity component. A provision is made to inject a certain fraction of the PAN component with help of multiplication factor k. When full radiometric fidelity is used, the k takes value of 1. In this study, the value of k is set at 1. The various parameters are shown in table 1. The original PAN and MS images and those obtained after fusion using various methods are shown in fig. 2 for one sub-image of 512x512 pixels. The variations of statistical parameters are shown in the fig. 3. The results of applying to the other four sub-images are almost similar. To get the best fused image, the spectral correlation CC should be near one. But in practice, higher spatial resolution is obtained at the cost of spectral correlation. The table list the values which are typical of those obtained when applied to other sub-images.

For good fusion algorithm, the SNR should be as high as possible. It indicates signal and noise can be distinguished. NRMSE should be low; it indicates difference between fused image and actual image which is low. As seen in figure 3 and table 1, NRMSE is very small and almost constant. For evaluation of the performances, the averages of the parameters of the R, G and B components were considered. The methods were sorted in terms of these vital parameters. From the analysis of statistical data of all the 5 subsets, it is observed that IHS5 method is, in general, the best performer,

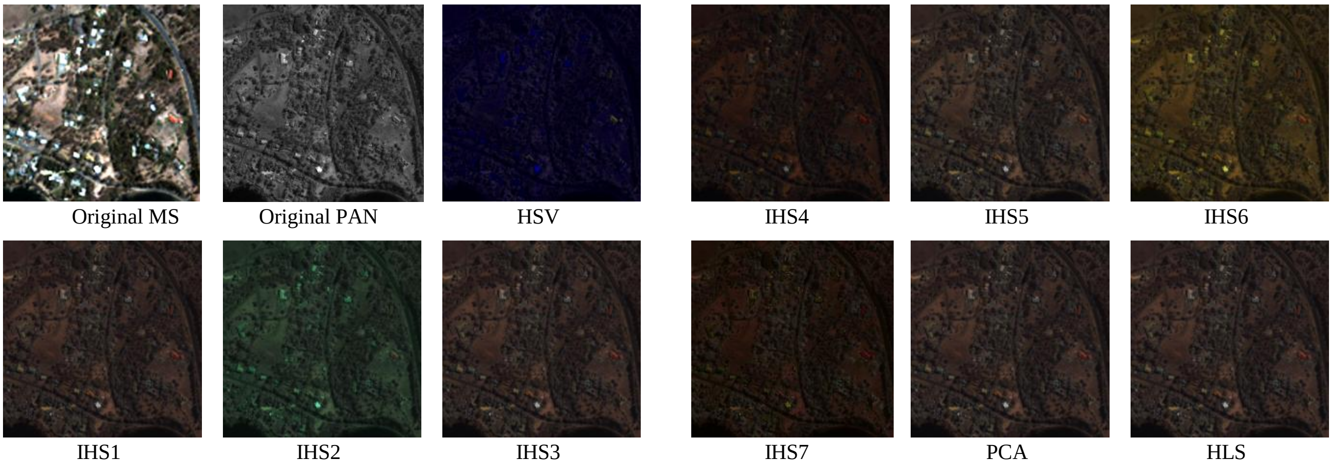

Fig.2 Original and Fused Images

followed by IHS6, and then IHS3 or ISH4 as evaluated based on all parameters. ISH5 method gives has SNR and CC nearer to one. Also, this method shows highest entropy and SD implying highest information content. The DI values are in general low for these above methods. The PCA method which considers the NIR band also, gives good results as expected. The ISH5 method and PCA method performances are nearly equal. The PCA method acts as a reference for evaluation.

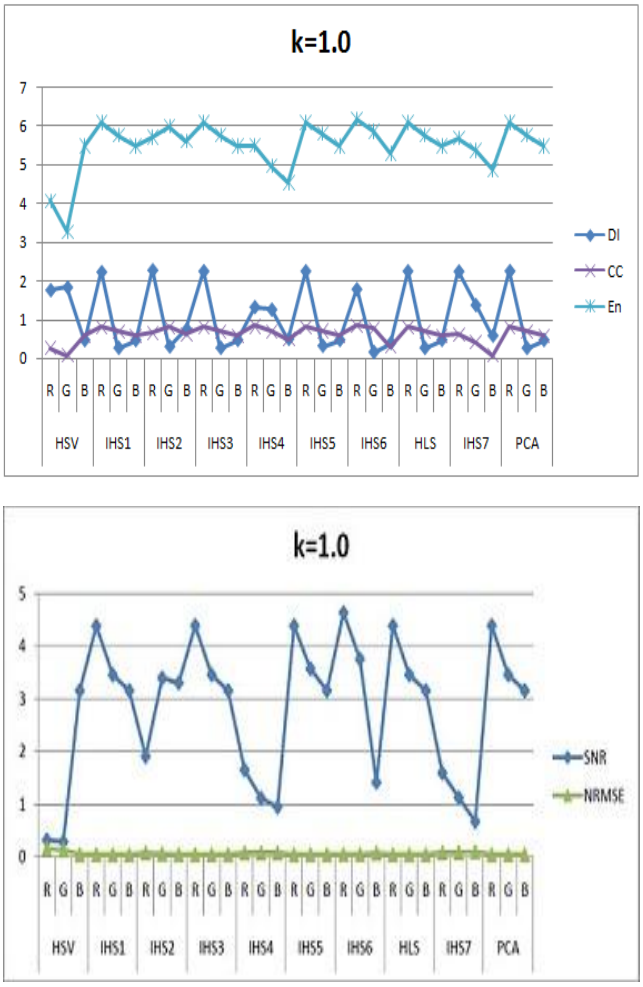

Fig.3. Comparison of the statistical parameters from different methods.

Table1. Quality assessment parameters

METHOD	Band	SNR	NRMSE	EN	$DI \times 10^3$	CC	SD
HSV	R	0.3127	0.1550	4.0648	1.7711	0.2569	9.0084
	G	0.2795	0.1286	3.2803	1.8424	0.0885	7.4395
	B	3.1572	0.0422	5.4744	0.4721	0.5768	11.7755
IHS1	R	4.3874	0.0422	6.0706	2.2434	0.8068	17.1473
	G	3.4536	0.0422	5.7500	0.2733	0.7071	14.0687
	B	3.1572	0.0422	5.4744	0.4721	0.5768	11.7755
IHS2	R	1.9074	0.0706	5.7016	2.2896	0.6584	13.1774
	G	3.3938	0.0545	5.9758	0.3066	0.8050	16.7039
	B	3.3039	0.0434	5.6100	0.7516	0.6117	12.8122
IHS3	R	4.3888	0.0422	6.0711	2.2630	0.8068	17.1498
	G	3.4556	0.0422	5.7503	0.2716	0.7074	14.0721
	B	3.158	0.0422	5.4751	0.4781	0.5770	11.7782
IHS4	R	1.6493	0.0728	5.4917	1.3312	0.8329	11.4204
	G	1.1067	0.0728	4.9667	1.2639	0.7020	8.1929
	B	0.9402	0.0727	4.5279	0.5064	0.4900	6.2080
IHS5	R	4.3889	0.0422	6.0711	2.2644	0.8068	17.1501
	G	3.5731	0.0423	5.7938	0.3250	0.7173	14.4362
	B	3.158	0.0422	5.4751	0.4781	0.5770	11.7782
IHS6	R	4.6397	0.0444	6.1609	1.7954	0.8448	18.4392
	G	3.7527	0.0444	5.8524	0.1617	0.7701	15.3486
	B	1.4122	0.0653	5.2900	0.4012	0.2991	10.0214
HLS	R	4.3889	0.0422	6.0711	2.2644	0.8068	17.1501
	G	3.4556	0.0422	5.7503	0.2718	0.7074	14.0721
	B	3.158	0.0422	5.4751	0.4781	0.5770	11.7782
IHS7	R	1.5909	0.0789	5.6785	2.2567	0.6233	12.9277
	G	1.1207	0.0787	5.3620	1.3826	0.4113	10.7533
	B	0.6683	0.0939	4.8541	0.5905	0.0836	9.6763
PCA	R	4.3892	0.0422	6.0711	2.2665	0.8068	17.1506
	G	3.4556	0.0422	5.7503	0.2712	0.7074	14.0723
	B	3.1575	0.0422	5.4745	0.4756	0.5768	11.7743

VI. CONCLUSIONS

This study shows that the various fusion methods introduce wide ranging spectral distortions. Retention of high spatial frequency components from PAN into MS, invariably leads to high spectral distortions. The present study shows that, when these methods are applied to the IKONOS-2 Pan and MS data, the IHS5 methods performs best followed by IHS6, IHS3 or ISH4. The IHS6 method proposed by LI, Kwok and Wang [9] in 2002 applies discrete wavelet frame transform technique. The IHS6 method proposed by Hsu et al. [10] in 2009 uses artificial neural network technique. The observations of this study are almost similar to those of [3] based on the IRS Cartosat PAN and Landsat TM MS data. According to [3], the IHS5 method is best performer followed by HLS and IHS4. The PCA method which considers the NIR band also, gives good results as expected. The ISH5 method and PCA method performances are nearly equal. The PCA method acts as an indirect reference for evaluation. More studies of this type need to be carried out on various types of data acquired from multi-sensor, multi-platform, multi-date, multi-view geometries etc. Also, the use of fusion MS data in quantitative analysis need to be further explored.

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