Image Fusion for Improving Spatial Resolution of Multispectral Satellite Images

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Abstract — This paper demonstrates implementation and evaluation of the image fusion techniques applied on the panchromatic and multispectral 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 panchromatic and multispectral images, fusion algorithms, such as PCA and wavelet algorithms have been employed and analyzed. In this paper, performance evaluation criteria are also used for quantitative assessment of the fusion performance. The spectral quality of fused images is evaluated by the Deviation Angle, Spectral Angle, Correlation Index, ERGAS, Q4 and RMSE. The analysis indicates that the DWT 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 panchromatic and multispectral image fusion.

Index Terms— Image fusion, Panchromatic images, Multispectral images, PCA, Wavelet, HIS, ERGAS, Q4

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1 INTRODUCTION

INFORMATION Fusion is a naturally occurring phenomenon in most biological systems. Data from various sources are merged in order to make optimal decisions. International society of information fusion aptly defines it as – "Information fusion encompasses the theory, techniques and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources such that the resulting decision or action is in some sense better than would be possible if any of these sources were used individually without such synergy exploitation"[1] Image Fusion is a similarly inspired effort to merge relevant visual data sets which are dependent and yet have disparity to certain extent in order to come up with a smaller data set apt for a better semantic interpretation of data for a given application.[3] In the field of remote sensing, satellite images are captured in various frequency bands with different spatial, temporal and spectral resolutions.[12] The data acquired from all these sources have a disparity in nature and images of same locations have spatial dependency.[6] This situation is exploited by image fusion algorithms to come up with merged images which are more detailed and information rich than any of the individual images.

Due to physical constraint, there is a tradeoff between spatial resolution and spectral resolution of a high resolution satellite sensor, 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 (IRS-P5: panchromatic image, 1m, IRS – P6 multispectral image 4m).[9] 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. 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.[7] The images varying in spectral, spatial and temporal resolution may give a more comprehensive view of the observed objects.

Image fusion has been extensively used in the past on remote sensing data for various applications. Some of them are Sharpening of images, improving geometric corrections,[6] providing stereo viewing capabilities for stereo photo grammetry, Enhancing features not fully visible in either of the single data alone, Detect changes using multi-temporal data.

Even though advances in sensor technology have been able to provide very high quality imagery, certain natural conditions such as cloud cover and weather and reflectance properties of different objects limit the final quality of information gathered from the images. Image fusion thus plays an important role in realizing practically useful applications from the remote sensing data.

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)
3. Pyramid based Methods such as Laplacian Pyramid
4. Wavelet Methods using powerful haar wavelets.

This study analyzes current image fusion techniques to assess their performance. The image fusion methods used include Standard IHS, PCA 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 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. 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.

In wavelet fusion method First, three new panchromatic images are produced according to the histogram of R, G, and 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). [12] 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).
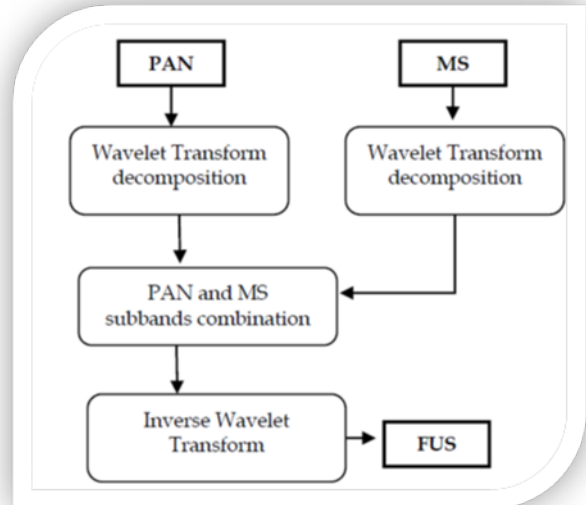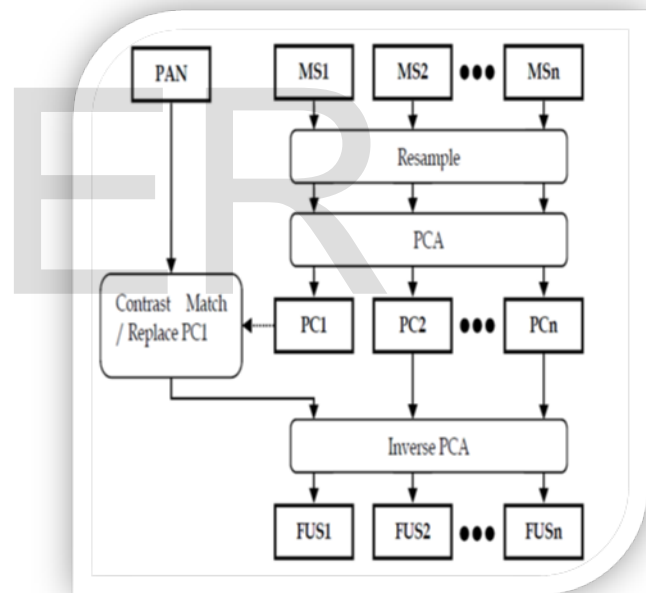

Fig   1. Block diagram of Wavelet fusion

Fig   2. Block Diagram of PCA Fusion

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, state-of-art evaluation criteria are used for 9.5

3.1 Root Mean Squared Error (RMSE)

The root mean squared error (RMSE) displays spectral distortion of the fused band when compared with the original low spatial resolution data. It is computed by the difference of the standard deviation and the mean of the fused and the original image. The best possible value is again 0.

$$RMSE = \sqrt{\frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (I_r(i,j) - I_f(i,j))^2} \tag{1}$$

In the above equation, M and N are matrix sizes for the reference and fused images, respectively.

3.2 Relative Global Dimensional Synthesis Error (ERGAS)

The formula for Relative Global Dimensional Synthesis

$$ERGAS = 100 \frac{h}{\ell} \sqrt{\frac{1}{n} \sum_{i=1}^{n} \frac{RMSE_i^2}{MR_i^2}} \tag{2}$$

Where MRi is the mean radiance of the ith MS band, h is the spatial resolution of the high resolution image, l is the spatial resolution of the low resolution image. ERGAS offers a global depiction of the quality of radiometric distortion of the fused product. The lower the value of the RMSE index and the ERGAS index, the higher the spectral quality of the fused images.

3.3 Universal Image Quality Index (Q-average)

Quality Index (QI) is a metric that is used in order to evaluate the quality of monochrome images. Q4 is a generalization of QI by extending it to be calculated for hypercomplex numbers, or quaternions, representing the spectral pixel vectors. Q4 is defined as

$$\begin{aligned} Q4 &= \frac{4|\sigma_{rf}| \cdot |\bar{r}| \cdot |\bar{f}|}{(\sigma_r^2 + \sigma_f^2)(|\bar{r}|^2 + |\bar{f}|^2)} \\ &= \frac{|\sigma_{rf}|}{\sigma_r \sigma_f} \frac{2|\bar{r}| \cdot |\bar{f}|}{|\bar{r}|^2 + |\bar{f}|^2} \frac{2\sigma_r \sigma_f}{\sigma_r^2 + \sigma_f^2} \end{aligned} \tag{3}$$

The first term measures the alignment of the spectral vectors and as such detects where radiometric distortion is accompanied by spectral distortions in a single factor. The second term measures the luminance distortion and the third measures the contrast distortion. Q4 factor is calculated over a window of M-by-M which is normally selected as M=16 or M=32. Q4 is averaged over the whole image to lead a global quality metric. Q4 is in the range [0; 1] where one represents the ideal fusion that is when the fused image and the reference image are identical.

4   EXPERIMENT DATA AND ANALYSIS OF FUSION RESULTS

4.1 Experiment Data

The image fusion techniques applied on the IRS-P5 (panchromatic) and IRS-P6 (Multispectral) 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. Below figures 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.

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.

Fig 3 .Multispectral Image of IRS-P6

Fig   4. Panchromatic Image of IRS-P5

Fig   6. PCA Based Image Fusion Result

Fig   5. WT Based Image Fusion Result

TABLE 1
PARAMETERS

Parameter	PCA Based Fusion		WT Based Fusion	
ERGAS	129.2809		111.6863	
Q 4	8 by 8	0.43337	8 by 8	0.44466
	16 by 16	0.52693	16 by 16	0.54496
	32 by 32	0.56941	32 by 32	0.59173

5   CONCLUSIONS

From the above analysis and comparison, we can conclude that PCA 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 Panchromatic and Multispectral images. In PCA and Standard IHS image fusion, dominant spatial information and weak color information is an often problem, Therefore are suited for visual interpretation, image mapping, and photogrammetric purposes wavelet Transform based on haar 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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