Study on the Spectral Quality Preservation Derived from Multisensor Image Fusion Techniques between JERS-1 SAR and Landsat TM Data

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Abstract—The advantage of multisensor data fusion stems from the fact that the use of multiple types of sensors increases the accuracy with which a quantity can be observed or characterized. The response of radar is more a function of geometry and structure than surface reflection as occurs in the optical wavelengths. A suitable fusion method has to be chosen with respect to the used spectral characteristic of the multispectral bands and the intended application. This paper describes a comparative study of multisensor image fusion techniques in preserving spectral quality of the fused images. Image fusion techniques applied in this study are: wavelet, intensity-hue-saturation (IHS), principal component analysis (PCA), and high pass filtering (HPF). With these image fusion techniques, a higher spatial resolution JERS-1 SAR is fused with Landsat TM data. The merging process is carried out at the pixel level and the comparison of the resulting images is explained based on the measurement in preserving spectral quality of the fused images. Assessment of the spectral quality is performed by graphical and statistical methods between original TM image and the fused images. The factors computed to qualify the fused images are: mean, standard deviation, coefficient correlation, and entropy. With a visual inspection, wavelet and PCA techniques seem to be better than the other techniques. PCA provided the greatest improvement with an average entropy of about 5.119 bits/pixel.

Keywords—multisensor data fusion; intensity-hue-saturation; principal component analysis; high-pass filtering; spectral quality.

I. INTRODUCTION

The advantage of multisensor data fusion stems from the fact that the use of multiple types of sensors increases the accuracy with which a quantity can be observed or characterized. Further, it reduces the effect of noise on the measured quantity. The response of radar is more a function of geometry and structure than surface reflection as occurs in the optical wavelengths [7]. The combined optical and microwave data provide a unique combination that allows more accurate identification, as compared to the results obtained with the individual sensors [1].

A suitable fusion method has to be chosen with respect to the used spectral characteristic of the multispectral bands and the intended application. For a classification purpose the importance is to preserve the spectral information whereas the other applications depend on a sharp and detailed display of the scene.

This paper describes a comparative study of multisensor image fusion techniques using wavelet, intensity-hue-saturation (IHS), principal component analysis (PCA) and high pass filtering (HPF). Specifically, the effort of image fusion is conducted at the pixel level. Fusion at the pixel level involves accurate registration of the different sensor images before applying a combination operator to each set of registered pixels. Spatial registration accuracies should be at the subpixel in order to avoid combination of unrelated data, making this approach the most sensitive to registration errors [7].

II. TEST AREA, IMAGES ACQUISITION AND PREPROCESSING

The test site chosen for this study is Bandung, which is located in 107°26'00"E - 107°34'00"E and 06°51'30"S - 06°58'30"S, covering an area of about 122 Km². The JERS-1 SAR image employed for this study was acquired on 22 June 1994 and Landsat TM on 4 July 1994.

The wavelet transform applied in this study is a two dimensional Discrete Wavelet Transform (DWT). The original image is reduced in resolution by successive low-pass filter and subsampling. The three details images are a set of independent, spatially oriented frequency channels that detail vertical high frequencies, horizontal high frequencies, and cross-directional high frequencies [6]. The source images are decomposed by DWT to the same resolution. After the wavelet transform the detail coefficients of the more highly resolved band (JERS-1 SAR data) and the approximation coefficients of the multispectral image (Landsat TM data) are used to create the synthetic wavelet image. Finally, the more highly resolved multispectral image is created using the inverse DWT.

IHS concept is based on the representation of low-resolution multispectral images in the IHS system and then substituting the I component with the high spatial resolution image. The Intensity component—the sum of the bands—is replaced with a stretched higher spatial resolution value (JERS-1 SAR data) and performing an inverse IHS transform. An inverse IHS transformation produces a new high resolution multispectral image.

In PCA, the original inter-correlated data are mathematically transformed into new, uncorrelated images called components
or axes [2]. PCA is a relevant method for merging remotely sensed imagery because of its ability to reduce the dimensionality of the original data from n to 2 or 3 transformed principal component images, which contains majority of information. PCA in image fusion has two approaches: a) first PC of multi-channel image was replaced by different sensor image, b) all multi-image data channels were used as input to PCA procedure.

The HPF method introduced by [10] extracts edge information of the high resolutions image which is then added to the low resolution channel on a pixel by pixel basis. The high pass filter of the high resolution image corresponds to its high frequency component which is mostly related to the spatial information. Hence, by adding this filter to the low resolution channel some of the high spatial information content of the high resolution image will become apparent in the fused product [9].

All sensor-specific corrections and enhancement of image data have to be applied prior to image fusion. Any spatial enhancement performed prior to image fusion will benefit the resulting fused image. The JERS-1 image is first registered to map coordinates and resampled by cubic convolution. The Landsat TM image is then registered by image-to-image procedure directly to their corresponding JERS-1 images and was resampled at the same resolution, also by cubic convolution, in order to avoid the blockiness due to the enlargement process. A minor coregistration error can lead to a slightly mismatched edge (edge-blurring problem).

The pre-processed Landsat TM and JERS-1 data were merged using wavelet, IHS, PCA and the combined PCA and HPF techniques (PCA+HPF). In the first PCA technique, all channels of Landsat TM (Figure 2(a)) and JERS-1 (Figure 2(b)) were used as input to PCA. In the PCA+HPF technique the high pass filtered JERS-1 data was inserted into the three channels of the PCA product from Landsat TM image.

During the analytical step, the original and the fused images were evaluated to assess the improvement in spectral quality derived from these techniques.

III. SPECTRAL QUALITY ASSESSMENT

In order to assess the improved spectral quality of the image fusion effectively, the resulting images were compared with the original Landsat TM bands. Although the result of the fusion visually looks satisfactory, its spectral truth remains to be checked quantitatively in order to evaluate precisely the performance of each applied fusion technique. The comparison was performed by graphical and statistical interpretation. The graphical comparison is performed to show a spectral effect between original and the fused images. Grey level values were measured in each of the images. These values are average values of 5 by 5 pixels. The graphical comparisons provide a band combination and point-by-point analysis.

The factors computed to qualify the fused results are as follows: mean, standard deviation, coefficient of correlation, and entropy. Standard deviation globally indicates the level of error at any pixel. Ideally, it should be null. Correlation coefficient reveals the similarities in small size structures between the original and the fused images.

The correlation should be high so that objects that were bright in the original bands are also bright on the fused images. It should be as close as possible to 1. However, it does not allow one to estimate the amount of information incorporated in multispectral images. Therefore, an additional measurement is used based on the entropy information. Entropy is a quantitative measurement of information content of an image. Entropy sees information as a frequency of change in the digital numbers in images [5]. The larger the entropy, the more is the information quantity the image has. Shannon's entropy formula in evaluating the information content of an image is modified as [3]:

$$H = - \sum_{n=0}^{255} p_n \log p_n$$ (1)

where $p_n$ is the histogram distribution of the image. For an 8-bit image ranges between 0 to 255, the maximum entropy is 8 bits/pixel.

IV. ANALYSIS AND COMPARISONS

Figure 2(c), (d), (e) and (f) show the resulting images from the techniques mentioned above. In the fused images, local contrasts are much reinforced. They almost have the spatial quality as that of JERS-1 SAR. However, the colorful appearances of the resulting images are somewhat different from the original one. The resulting images lead to a modification of colours. With a visual inspection, the results of the image fusion with wavelet and PCA techniques seem to be better than IHS and PCA+HPF, since more features are incorporated in these fused images. Linear and small shapes features were reinforced. Street, urban areas, paddy field, river, water areas etc. can be clearly recognized.

Grey level values of four landcover classes were measured in the original and fused images for graphical comparison of the spectral effects of the fused techniques described above. Figure 1(a), (b), (c), and (d) are the feature space plots showing the original image data alongside the four data fusion models for each scene. Feature space plots showing three channels (Red, Green, and Blue) in the X axis and brightness value in the Y axis for all techniques. As can be seen from figures, each of the image fusion techniques tend to modify the distribution of brightness values. The PCA technique has almost similar distribution of pixels as compared to the wavelet image. The spectral curves of the measured landcovers, such as road, water and forest, are observed to be closer. However, in the forest landcover area, IHS spectral curve has a similar fashion to that of the original image. Within the distribution though, PCA and wavelet techniques tend to eliminate brightness values in a systematic linear fashion.

The statistical computation results are presented in Table 1. It shows that the corresponding values of the different assessment criteria were measured for the original and fused images. The IHS technique tends to decrease the mean and produce high standard deviation for all channels. The PCA+HPF fused image results are less increased compared to the original images, as expressed by their coefficient correlation.
The average entropy of Landsat TM original channels, wavelet, IHS, PCA and PCA+HPF are 3.264, 4.665, 4.406, 5.119 and 4.782 bits/pixel respectively. The increased entropy indicates the enhancement of information content through the wavelet, IHS, PCA and PCA+HPF techniques, and the PCA has provided the greatest improvement in all multispectral images with an average entropy of 5.119 bits/pixel. The enhancement of information contains more useful information on the images.

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<tbody>
<tr>
<td>Original image</td>
<td>R 85.924</td>
<td>22.293</td>
<td>3.456</td>
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<td></td>
<td>G 113.562</td>
<td>16.660</td>
<td>2.859</td>
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<tr>
<td></td>
<td>B 113.963</td>
<td>13.240</td>
<td>3.476</td>
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<tr>
<td>Wavelet</td>
<td>R 111.829</td>
<td>62.471</td>
<td>0.822</td>
<td>5.263</td>
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<tr>
<td></td>
<td>G 123.490</td>
<td>59.840</td>
<td>0.778</td>
<td>4.703</td>
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<td></td>
<td>B 92.526</td>
<td>48.296</td>
<td>0.615</td>
<td>4.028</td>
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<tr>
<td>IHS</td>
<td>R 114.289</td>
<td>67.200</td>
<td>-0.287</td>
<td>5.408</td>
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<tr>
<td></td>
<td>G 51.700</td>
<td>37.074</td>
<td>0.207</td>
<td>4.803</td>
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<td>B 52.086</td>
<td>61.653</td>
<td>0.060</td>
<td>3.007</td>
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<tr>
<td>PCA</td>
<td>R 125.174</td>
<td>58.138</td>
<td>-0.331</td>
<td>5.220</td>
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<tr>
<td></td>
<td>G 127.340</td>
<td>52.984</td>
<td>-0.511</td>
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<td></td>
<td>B 126.971</td>
<td>31.389</td>
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<tr>
<td>PCA+HPF</td>
<td>R 126.335</td>
<td>54.724</td>
<td>-0.540</td>
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<tr>
<td></td>
<td>G 125.543</td>
<td>32.322</td>
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<td>B 125.591</td>
<td>20.394</td>
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V. CONCLUSION

Two multi-resolution images were fused with the aim of producing enhanced multi-spectral channels preserving most of the spectral information content of the original images. The results of the wavelet, PCA and PCA+HPF can clearly recognize details of objects. Image fusion accomplished by PCA was superior compared to other methods in its ability to identify water bodies. According to this study, the visual and quantitative assessment of the spectral quality of the fused images demonstrated that the PCA fusion technique can improve the spatial quality and preserve spectral characteristics compared to the other techniques. Since our study used images with rather coarse spatial resolution, our findings in spatial quality assessment should be reexami ned with higher spatial resolution images. Therefore, the spatial detail of objects can be clearly detected and analyzed.

REFERENCES


Figure 1. Brightness values and spectral responses in each landcover

Figure 2. Image comparison between original and fused results