A Quality of Images Fusion for Remote Sensing Applications

Yuhendra*1, Josaphat Tetuko Sri Sumantyo2
1Department of Informatics, Faculty of Engineering, Padang Institute of Technology, Indonesia
2Microwave Remote Sensing Laboratory, Chiba University, Japan
*Corresponding author, email: yuhendrasan@gmail.com

Abstract

Image fusion is a useful tool for integrating low spatial resolution multispectral (MS) images with a high spatial resolution panchromatic (PAN) image, thus producing a high resolution multispectral image for better understanding of the observed earth surface. It has become an important issue for various remote sensing (RS) problems such as land classification, change detection, object identification, image segmentation, map updating, hazard monitoring, and visualization purposes. When applied to remote sensing images, a common problem associated with existing fusion methods has been the color distortion, or degradation in the spectral quality. The main proposed of this research is to evaluate the quality of fused images for object identification. We examine the effectiveness of the following techniques multi-resolution analysis (MRA) and component substitution (CS) fusion. In order to improve this situation, the second purpose of this work is to establish an automatic and reliable way for the evaluation of the fused images, on the basis of both qualitative and quantitative metrics. In this result, It is found that the CS fusion method provides better performance than the MRA scheme. Quantitative analysis shows that the CS-based method gives a better result in terms of spatial quality (sharpness), whereas the MRA-based method yields better spectral quality, i.e., better color fidelity to the original MS images.

Keywords: Image fusion, multispectral, panchromatic, object identification, fast Fourier transform (FFT) - enhanced IHS (FFT-E)

Copyright © 2016 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

The recent increase in earth observing satellites such as Geo-Eye, Worldview, Quickbird, Ikonos, Landsat, EO-1(ALI sensor) has led to the availability of high resolution images of various types fromRemote Sensing (RS). The availability of a variety of airborne as well as space-borne sensors has led to various data sets of different spatial, spectral and temporal resolutions. Most of these sensors have multispectral (MS) and panchromatic (PAN) images. In contrast, the panchromatic (PAN) image is a grayscale image, but its wide spectral coverage makes it possible to attain much higher spatial resolution [1]. The high spatial information content of PAN images is well-suited for intermediate scale mapping and urban classification studies [2, 3]. Although the combinatory analysis of MS and PAN images can, in principle, provide all the spatial and spectral features concerning the target pixels, better interpretation of high-resolution satellite imagery can often be attained using a pan-sharpened image that is obtained through image fusion [4, 5].

Image fusion is also known as pan-sharpening, resolution merge, image integration, or multi-sensor data fusion [5, 6]. It can be used to combine images of different spatial resolutions to enhance the resolution of high resolution PAN image with low resolution MS images to providing high-spatial resolution and high spectral resolution remote sensing images [8, 9], see the Figure 1. The issued of image fusion in RS problems such as land classification, change detection, object identification, image segmentation, map updating, hazard monitoring, and visualization purposes. Image fusion can be applied both to data recorded by different sensors (multi-sensor image fusion), data recorded by the same sensor scanning the same scene at different dates (multi-temporal image fusion), data recorded by the same sensor operating in different spectral bands (multi-frequency image fusion), data recorded by the same sensor at different polarizations (multi-polarization image fusion), and data recorded by the same sensor located on platforms flying at different heights (multi-resolution image fusion).
In the fusion techniques, So far many researchers have addressed the problem of multiresolution image fusion for RS applications, proposing different pan-sharpening methods [9]. The improvement of existing methods, comparison and evaluation of various methods with respect to spectral quality preservation and spatial enhancement for different types of data sets has been discussed such as intensity-hue-saturation (IHS) [10, 11], color normalized (CN) Brovey [12-13] and principal component analysis (PCA) [14]. Other methods such as Gram-Schmidt (GS) [15], synthetic variable ratio (SVR) [16-18] and high pass filtering (HPF) [1] rely on the intensity modulation. In addition, several researchers have proposed the use of wavelet transform [19-20] or discrete wavelet transform [21] to extract geometric edge information from PAN images and registration combines with transformation [22]. The IHS, CN-Brovey, and CN-spectral techniques are the most commonly used algorithms in RS applications.

Concerning various methods developed for image fusion for remote sensing, it is desirable to give a general assessment of the quality of the fused images from the viewpoint of practical use. In this paper, we use fusion algorithm to assess the capability of fusion using multi-resolution analysis (MRA) and component substitution (CS) algorithm to observe of fused image for better quality in object identification. Also, we apply the following statistical approaches for standardizing and automating the evaluation process of the fused images. First, qualitative assessment is made with conventional visual inspection. Then, we examine the spectral quality between the original MS and the fused images.

![Figure 1. Concept of image fusion](image)

**Figure 1. Concept of image fusion**

### 2. Study Area and Satellite Data

The study site for this work is located in Kolkata area (88°20'27.84"E, 22°32'45.67"N), India, obtained in November 2004 and distributed in the Global Land Cover Facility (http://glcf.umiacs.umd.edu/index.shtml). The PAN sensor collects information in the visible and near infrared wavelengths of 0.45-0.90 µm. The area covered in this imagery is mainly an urban area with a structured road, water, roof, tree, shadow and grass. The spectral bands information of sensors was shown in Table 1.

<table>
<thead>
<tr>
<th>Sensor name</th>
<th>Band Name</th>
<th>Spectral Range (nm)</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QuickBird</td>
<td>Band 1- Blue</td>
<td>450-520</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Band 2- Green</td>
<td>520-600</td>
<td>2.44-2.88</td>
</tr>
<tr>
<td></td>
<td>Band 3- Red</td>
<td>630-690</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Band 4 – NIR</td>
<td>760-900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Panchromatic</td>
<td>450-900</td>
<td>61 -72 cm</td>
</tr>
</tbody>
</table>

**Table 1. The spectral bands information of optical sensor QuickBird satellite imagery**
3. Research Method

3.1. Spectral Response and Range of Sensor

Significant spectral distortion in image fusion occurs due mainly to the wavelength extension of the new satellite PAN sensors. Table 1 and Figure 2 show the spectral band and spectral response of satellites QuickBird sensors. In image fusion techniques, it is important to include sensor spectral response information [1], since, first, in order to preserve physical meaning of merged spectral bands, the sensor spectral response for each band has to be taken into account and second, image fusion techniques aim at recovering the image obtained by an ideal virtual sensor with the same spectral sensitivity of the MS and spatial resolution of the PAN sensor.

3.2. Spatial Resolution Ratio

The spatial resolution ratio improvement can make a sharpen image while preserving spectral information contained in the fused images. Since PAN images usually have a better spatial resolution than the multispectral images of the same sensor, while the MS images provide spectral properties of the objects. In image fusion, spatial resolution ratio plays an important role in image fusion. The spatial resolution ratio can be defined as the ratio between the spatial resolution of the high resolution PAN image and that of the low resolution MS image [23]. The both of spatial resolution ratio of PAN to MS image 1:4. It is often a challenge fused images with such a high spatial resolution ratio.

3.3. Band Selection Processing by the OIF

Band selection is a key step of fusion techniques. For this purpose, values of optimum index factor (OIF) are useful for designating the most favorable band combination according to their information [24]. Generally, a larger standard deviation of an image infers that it involves more information. Thus, the OIF is defined [25] as:

$$OIF = \frac{1}{3} \frac{\sigma_i}{\sum_{j=1}^{3} | r_{ij} |},$$

Where $\sigma_i$ is the standard deviation of each of the three selected bands and $r_{ij}$ is the correlation coefficients (CCs) between any pair formed by these bands (Table 2).

3.4. Re-sampling

The most important prerequisite for accurate data fusion is precise geometric correction. The GeoEye-1 image has been geometrically corrected and registered to WGS 84 datum with the Universal Transverse Mercator (UTM) zone 45 projection. A QuickBird image also has been geometrically corrected and registered to WGS 84 datum with the UTM zone 55S projection. Since the PAN and MS images were taken at the same time with the same sensor, data fusion can be carried out directly without further registration. Next, we apply re-sampling, in which each data point (pixel) in the high-resolution base map is assigned with a value based on the
MS image pixels using the nearest neighbor technique. In this way, we are combined a PAN and MS images with 0.7 m, 2.8 m spatial resolution are re-sampling produced from QuickBird images, respectively (Figure 3).

3.5. Image Fusion Algorithm
In the present analysis of QuickBird images, pixels of PAN and MS images are fused by using an algorithm specifically developed for very high resolution satellite images. In order to improve the quality of spatial and spectral information, two main approaches of fusion, namely MRA and CS, are compared in the present analysis. These methods have been chosen here, since they can yield less spectral distortion as compared with other fusion methods such as IHS, PCA, Brovey, and wavelet [4, 26]. In the following part of this section, we briefly describe the essential aspects of these methods.

3.5.1. Multi-resolution Analysis (MRA)
MRA is an approach based on fast Fourier transform (FFT)-enhanced intensity-hue-saturation (IHS) transformation. Since this methods is capable of preserving the spectral characteristic, generally it is suitable for image analysis purposes [8-10]. The re-sampled multispectral images are transformed from the RGB to IHS color space to obtain the intensity (I),
hue (H), and saturation (S) components, and low-pass filtering (LPF) is applied to the intensity component. After high-pass filtering (HPF), the PAN image is added to the low-pass filtered intensity component by means of inverse FFT (FFT⁻¹). Finally, inverse IHS transformation (IHS⁻¹) is performed on the IHS image to create the fused image.

3.5.2. Component substitution (CS)

All fusion methods which do not make use of a filtering process to extract the high frequency details from the PAN image fall in the category of component substitution methods. The principle idea is to add the details of the PAN image into the MS images making use of some transformation. Gram-Schmidt (GS), Intensity-Hue-Saturation (IHS) based fusion methods, Brovey transform based fusion, PCA based fusion, all fall in the category of CS or Component Substitution Methods.

3.6. Spectral Quality

The quality of fused image was assessed by means of some quality measures that can predict perceived image quality automatically. In this work, two types of quality assessment approaches are taken, namely qualitative (visual analysis and quantitative methods. The visual analysis is based on the visual comparison of the color between the original MIs and the fused image and that of the spatial details between the original PI and the fused image. These methods inevitably involve subjective factors and personal preference that can influence the result of evaluation. While visual inspection has limitation due to human judgment, quantitative approach based on the evaluation of “distortion” that is brought about by the noise added to the fused image is more desirable for mathematical modeling [27].

In this work, a validation method is proposed based on a quality criterion, namely, the relative average spectral error (RASE) [28-29] and relative dimensionless global error (ERGAS) [30,31] parameter. It is based on root mean squared error (RMSE) [32] to estimation and chosen as a robustness criterion. This statistical parameter is often used for evaluation of fusion techniques. These parameters are defined as follows:

1) Relative Average Spectral Error (RASE) is used to estimate the global spectral quality of the fused images.

\[
RASE = \frac{100}{M} \left[ \frac{1}{n} \sum_{i=1}^{n} RMSE^2 (B_i) \right]^{1/2}
\]  

Where \( M \) is the mean radiance of the \( n \) spectral bands (\( B_i \)) of the original MS bands; \( RMSE \) is the root mean square error computed as:

\[
RMSE (B_i) = Bias^2 (B_i) + STD^2 (B_i)
\]

2) Relative Dimensionless Global Error in Synthesis (ERGAS) was proposed by Wald as a multi-modal index to characterize the quality of process in terms of the normalized average error of each band of processed image. Increasing in ERGAS index may be the result of degradation in images due to fusion process. ERGAS index for the fusion is expressed as follow
These formulae can be used for comparing errors obtained from different methods, different cases and different sensors. Where \( \frac{dh}{dl} \) is the ratio between the pixel sizes of the PAN and MS images (e.g., 1/4 for QB and WV data), and \( \mu(i) \) is the mean of the \( i \)th band. Since ERGAS is a measure of distortion, its value must be as small as possible.

4. Results and Discussion

4.1. Quality Assessment

The quality of fused image was assessed by means of some quality measures that can predict perceived image quality automatically. In this work, two types of quality assessment approaches are taken, namely qualitative (visual analysis and quantitative methods. In the visual analysis, image quality is an important task in the evaluation, especially in the spectral quality. The spectral quality is denoted well the in pixel of the fusion images match the colors in the original MS is indicates well the sharpness of the image is retained compared to the PAN. A good fusion method have guarantee the preservation of the spectral information of the MS image. A preserve the color is important criterion in evaluating the performance of image fusion. In general, main fusion problem is color distortion has been reported by Zhang (Zhang, 2000). From visual comparison assessment, color combinations of MS bands are produced and analyzed using the optimum index factor (OIF), an index proposed by Chavez et al. [28]. Only three bands (R-G-B) can be employed from the four bands. Thus, these three spectral bands should be selected so as to project the multispectral information as efficiently as possible onto the final pseudo-color image, and this can be achieved by maximizing the OIF. For QuickBird, the maximum OIF (130.95) has been obtained with the same band combination of 2-3-4 as shown in Table 2.

Table 2. OIF index for bands combination the original MS images

<table>
<thead>
<tr>
<th>Satellite Sensor</th>
<th>Band Combination</th>
<th>( \sum \sigma_i )</th>
<th>( \sum r'_j )</th>
<th>OIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>QuickBird</td>
<td>123</td>
<td>90.74</td>
<td>2.87</td>
<td>31.51</td>
</tr>
<tr>
<td></td>
<td>124</td>
<td>163.49</td>
<td>2.17</td>
<td>75.16</td>
</tr>
<tr>
<td></td>
<td>134</td>
<td>165.56</td>
<td>2.08</td>
<td>79.52</td>
</tr>
<tr>
<td></td>
<td>234</td>
<td>184.2</td>
<td>1.40</td>
<td>130.95</td>
</tr>
</tbody>
</table>

Figure 6(a) shows the false-color composite of the 2-3-4 bands of QuickBird. The pansharpened images resulting from the five different image fusion techniques are shown in Figure 6. A major problem in image fusion is color distortion [30]. Preservation of color information is an important criterion in evaluating the performance of different image fusion methods. Before being compared with the original MS images (Figure 6(a)), the fused images must be re-sampled to match the resolution of the original MS image (Figure 3). Ideally, when a fused image is re-sampled, the original color information should be reproduced again [20]. The results in Figure 4 indicate that there is no apparent color distortion in all the fused images as far as the preservation of color information is concerned. Concerning the color preservation it is found that all fused image are closer to the original image. This means that all the techniques can preserve the spatial information for the fusion images.

Table 3 summarizes the correlation coefficients (CCs) for the QuickBird image between the original MS bands 2, 3 and 4 and the results obtained with different image fusion techniques. Here CCs are used to evaluate the spectral resemblance of two images and it can be seen from Table 3. And another test, we can examine the inter-band correlation that should be preserved in image fusion. Table 4 shows the comparison of the inter-band correlations (B2/B3, B2/B4, and B3/B4), among the original QuickBird image and between the original and fused images. values reasonably in agreement with those in the original MS images. From CCs, it is seen that fused images based on CS and MRA are well correlated with the original MS.
images. The results of the inter-band correlation (Table 4, on the other hand, indicate that GS fusion method gives results that show similarity with the original MS images.

Figure 6. Results of the false color composite of the QuickBird image: (a) composite of the 2-3-4 bands of the original MS images, and the results of different fusion techniques, with (b) CS and (c) MRA

Table 3. Spectral correlation for QuickBird

<table>
<thead>
<tr>
<th>Fusion Technique</th>
<th>Band 2 (0.52-0.60)</th>
<th>Band 3 (0.63-0.69)</th>
<th>Band 4 (0.76-0.90)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Image (MS)</td>
<td>0.937</td>
<td>0.941</td>
<td>0.951</td>
<td>0.943</td>
</tr>
<tr>
<td>CS</td>
<td>0.925</td>
<td>0.930</td>
<td>0.940</td>
<td>0.931</td>
</tr>
<tr>
<td>MRA</td>
<td>0.912</td>
<td>0.951</td>
<td>0.967</td>
<td>0.943</td>
</tr>
</tbody>
</table>

Table 4. Inter-band correlation

<table>
<thead>
<tr>
<th>Fusion Technique</th>
<th>Band 2-3</th>
<th>Band 2-4</th>
<th>Band 3-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Image (MS)</td>
<td>0.966</td>
<td>0.377</td>
<td>0.268</td>
</tr>
<tr>
<td>GS (CS)</td>
<td>0.961</td>
<td>0.367</td>
<td>0.244</td>
</tr>
<tr>
<td>FFT-E (MRA)</td>
<td>0.942</td>
<td>0.359</td>
<td>0.261</td>
</tr>
</tbody>
</table>

4.2. Performance Comparison using Spectral Quality

A thorough examination of spectral quality is made for fused images using the following spectral quality parameters: RMSE, ERGAS, PNSR and RASE. The fused image that best preserves the original spectral information, and hence exhibits the highest spectral quality, can be characterized with the following conditions: (i) the smallest values for the error parameters (RMSE, RASE and ERGAS), and (iii) the highest possible value of PSNR. Tables 5 summarize the results of the present analysis. In Table 5, we can see that the fused image based on GS exhibits the smallest the ERGAS and RASE errors when all bands are considered. Smaller values of spectral distortion given by PSNR (Table 6) are associated with high RMSE values in Table 7. On the basis of Table 5-7, one can conclude that, the CS (GS) method provides good spectral quality, preserving the spectral information contained in the original MS images than MRA (FFT-E) method.

Table 5. Global spectral information evaluation indicator of fused image

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fusion Techniques</th>
<th>QuickBird Band-2</th>
<th>QuickBird Band-3</th>
<th>QuickBird Band-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERGAS</td>
<td>CS</td>
<td>0.10</td>
<td>0.20</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>MRA</td>
<td>0.25</td>
<td>0.48</td>
<td>0.04</td>
</tr>
<tr>
<td>RASE</td>
<td>CS</td>
<td>15.35</td>
<td>25.69</td>
<td>11.02</td>
</tr>
<tr>
<td></td>
<td>MRA</td>
<td>9.50</td>
<td>12.09</td>
<td>23.55</td>
</tr>
</tbody>
</table>
Table 6. Evaluation of fused images with a distortion indicator (PSNR).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fusion Techniques</th>
<th>QuickBird Band-2</th>
<th>QuickBird Band-3</th>
<th>QuickBird Band-4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MRA</td>
<td>17.88</td>
<td>15.62</td>
<td>35.84</td>
</tr>
</tbody>
</table>

Table 7. Evaluation of fused images with spectral information indicators (bias and RMSE).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fusion Techniques</th>
<th>QuickBird Band-2</th>
<th>QuickBird Band-3</th>
<th>QuickBird Band-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>CS</td>
<td>2.23</td>
<td>2.47</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>MRA</td>
<td>5.77</td>
<td>7.48</td>
<td>0.73</td>
</tr>
</tbody>
</table>

5. Conclusion

In order to improve the spatial resolution and enhance structural/textural information while preserving the spectral information in MS images, two fusion methods of MRA and CS have been used for the quality assessment of the produced fused images. In both quantitative and qualitative results, it has been found that the CS based method leads to better spatial quality (sharpness), whereas the MRA based method better spectral quality (fidelity to the original color). In the future research, the methodology presented in this paper can be extended to include the fusion of optical and synthetic aperture radar (SAR) images from satellite remote sensing.

Acknowledgements

We would like to thank Global Land Cover Facility (GLCF) for providing the free download QuickBird data from (http://glcf.umiacs.umd.edu/index.shtml), and the anonymous reviewer for valuable comments and suggestions that helped in improving the clarity and quality of this paper.

References


