COMPARISON OF DIFFERENT IMAGE FUSION TECHNIQUES FOR INDIVIDUAL TREE CROWN IDENTIFICATION USING QUICKBIRD IMAGES

R. Riyahi[a,]*, C. Kleinn[a], H. Fuchs[a],

[a] Department of Forest Inventory and Remote Sensing, Georg-August-University, Göttingen, Germany.

(hriyahi, ckleinn, hfuchs)@gwdg.de

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ABSTRACT:

With the advent of a new generation of high resolution satellites, images are now available with less than 1 meter spatial resolution in panchromatic mode. For successful individual tree crown identification it is desirable to have images with both high spatial and high spectral resolutions. Fusion techniques are being developed to combine the clear geometric features of the panchromatic image and the colour information of the multispectral image. This paper compares the results of three different pixel based fusion techniques PCA (Principal Component Analysis), Brovey transformation and Ehlers transformation used to merge the multispectral information and Panchromatic data of QuickBird satellite imagery. The comparison is done based on visual and statistical analysis of the results. The area of interest is situated in Zagros forests, in southwest of Shiraz, Iran. Visual and statistical quality assessment of fused images showed that the PCA method performs better than the others.

1. INTRODUCTION

With the successful launch of the QuickBird satellite that provide high spatial resolution panchromatic image (Pan) of 0.61 m and multispectral images (MS) in four bands of 2.4 m spatial resolution, automatic extraction and identification of single trees by using satellite data attracts enormous research interests. For successful individual tree crown delineation and identification both high spatial and spectral information is essential. Because of some technical restrictions there is no operational system currently available that can provide high spatial resolution (MS) images directly. Most of the high-resolution satellites provide two types of image data: panchromatic imagery with high-spatial (but low spectral) resolution and multispectral images with lower spatial (but higher spectral) resolution. Image fusion techniques, as an alternative solution can be used to integrate the geometric detail of a high-resolution Pan image and the colour information of low-resolution MS images to produce a high-resolution MS image (Zhang, 2004). The primary objective of this paper is to apply three different fusion techniques on QuickBird data and evaluate the objective and subjective quality of fused images. The results and outcomes can help to find the best fusion method for individual tree crown identification using QuickBird images.

2. MATERIAL AND METHODS

2.1 Data characteristics and study area

The study site was located in the southwest of Shiraz,Iran with an area about 270 hectares which is covered mostly by oak trees. An open canopy structure with a small rainfed fields, bare soil, riverbeds and ploughed soils under the canopy are the main characteristics of Zagros forests. The rainfed wheat crop was harvested at the time of image acquisition so there was no visible biomass.

The QuickBird data were collected on July 01, 2005, at 10:54 local time. These images were cloud-free over the study area and no visible atmospheric effects were found. The characteristics of QuickBird satellite data used in this study are given in Table 1.

Type of Sensor	Band	Resolution (m)	Wavelength(μm)
Multispectral	1	2.4	0.45-0.52
	2	2.4	0.52-0.60
	3	2.4	0.63-0.69
	4	2.4	0.76-0.90
Panchromatic	-	0.6	0.45-0.99

Table 1. Characteristics of the QuickBird data.

2.2 Pre-processing

Accurate and precise co-registration of multispectral data with panchromatic image is the most important prerequisite for successful image fusion. Blurring edges in the fused images may arise from misalignment of features at the same location (Liu, 2000).The co-registration process implemented in this study was based on AutoSync extension of ERDAS IMAGINE 9.1 software which enables automatic image rectification. By using the panchromatic band as a reference image, the multispectral data were co-registered using ground control points (513 GCPs) and a second-degree polynomial geometric correction model with the nearest neighbour algorithm. The RMS error was 0.2 pixel. In order to generate similar pixel size to Pan the multispectral data were digitally enlarged by a factor of four in both directions. To avoid from blockiness effects the results were smoothed using a 3 by 3 low pass filter (Chavez et al., 1991).

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* Corresponding author.

2.3 Fusion method based on Principal Component Analysis (PCA)

This statistical technique converts inter-correlated multispectral bands into a new set of uncorrelated components, the so-called principal components (PCs) (Zhang, 2004). The first principal component PC1 accounts for maximum variance. The higher resolution image replaces PC1, since it contains the information which is common to all bands while spectral information is unique for each band (Pohl, 1999). It is assumed that Pan data is very similar to the first principal component image (Chavez et al., 1991). All four QuickBird bands are used as input to the principal component analysis. The Pan data is histogram matched with the first principal component. In the next step the first principal component is replaced by the stretched Pan image. Then the inverse PCA transform is performed to obtain multispectral high resolution imagery.

2.4 Fusion method based on Brovey transform

The Brovey transform is based on the mathematical combination of the multispectral images and high resolution Pan image. Each multispectral image is normalized based on the other spectral bands and multiplied by the Pan image to add the spatial information to the output image. The following equation shows the mathematical algorithm for the Brovey method (Zhang, 2002).

$$F_i = \frac{M_i}{\sum\limits_{j=1}^{N} M_j + c} \times P \qquad (1)$$

where F_i is a fused band

M_i is the multispectral band to be fused,

P is the Panchromatic band and

$\sum\limits_{j=1}^{N} M_j$ is the sum of all multispectral bands.

In some cases there it be an area with zero DN values for all bands; therefore a constant C has to be added in the denominator to produce meaningful output digital numbers.

2.5 Fusion method based on Ehlers transform

The basic idea behind this method is to modify the input Pan image to look more like the intensity component (Ling et al., 2007). In the first step in order to manipulating IHS components, three low resolution multispectral RGB bands are selected and transformed into the IHS domain. Then, the intensity component and the panchromatic image are transformed into the spectral domain via a two-dimensional Fast Fourier Transform (FFT). Low pass (LP) and high pass (HP) filter were directly performed in the frequency domain on the intensity component and the high resolution panchromatic image respectively. The idea is to replace the high frequency part of the intensity component with that from the Pan image (Ling et al., 2007). To return both components back into the spatial domain an inverse FFT transform was used. Then the high pass filtered panchromatic band and low pass filtered intensity are added and matched to the original intensity histogram (Ehlers, 2005; Ehlers et al., 2006). Finally, an inverse

IHS transform converts the fused image back into the RGB colour domain to obtain the high resolution multispectral image.

2.6 Visual comparison

Visual inspection has been done through different colour composites by a panel of investigators. A set of criteria and specifications were established regarding the spatial and spectral fidelity of objects with different shape and size. A mosaic of the all synthesized images was produced to guarantee that the same Look-up tables (LUTs) are applied to all images. This permits a comparison between any synthesized image and the original one.

2.7 Statistical comparison

In this study evaluation method from the work of Wald et al., 1997 was employed to assess the synthesis property of fused images. The fused images are re-sampled to the resolution of the original multispectral images.

Difference In Variances (DIV): The difference between original variance and the estimated is relative to the original variance. This difference expresses the quantity of information added or lost during fusion. A positive value indicates a loss of information and a negative value shows some added information. The ideal value is zero.

$$DIV = \frac{\delta_{MS}^{2} - \delta_{FMS}^{2}}{\delta_{MS}^{2}} \qquad (2)$$

where δ_{MS}^{2} is the variance of the original multispectral images and

δ_{FMS}^{2} is the variance of fused images.

Correlation Coefficient (CC): The correlation coefficient measures the closeness or similarity in small size structures between the original and the fused images. It can vary between -1 and +1. Values close to +1 indicate that they are highly similar while the values close to -1 indicate that they are highly dissimilar.

$$CC = \frac{\sum\limits_{i=1}^{N}\sum\limits_{j=1}^{N} (MS_{i,j} - \overline{MS})(F_{i,j} - \overline{F})}{\sqrt{\sum\limits_{i=1}^{N}\sum\limits_{j=1}^{N} (MS_{i,j} - \overline{MS})^2 \sum\limits_{i=1}^{N}\sum\limits_{j=1}^{N} (F_{i,j} - F)^2}} \qquad (3)$$

where CC is the Correlation Coefficient,

F is the fused image and i and j are pixels,

MS is the multispectral data.

Global errors: Global errors allow a comparison of all methods in a glance. Global evaluation indices ERGAS and RASE are used to evaluate quality of fused images. ERGAS is the acronym for "erreur relative globale adimensionnelle de synthèse", which means relative adimensional global error in

synthesis, is the normalized average error of each band. The ERGAS index for the fusion is expressed as follows:

$$ERGAS = 100 \frac{h}{l} \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[\frac{RMSE(B_i)^2}{(M_i)^2} \right]} \qquad (4)$$

where N is the number of bands involved in fusion, h/l is the ratio of the spatial resolution of original Pan and MS images.

M_i is the mean value for the original spectral image Bi.

$RMSE$ is the root mean square error computed between the degraded fused image and the original image.

Wald (2002) argued that ERGAS values larger than 3 stand for synthesized images of low quality, while an error ERGAS less than 3 represent a satisfactory quality.

RASE is the Relative Average Spectral Error (RASE) and characterizes the average performance of a method in the considered spectral bands. RASE is independent of units, the number of spectral bands, and accordingly of calibration coefficient and instrument gains. The value is expressed in percent and has a tendency to decrease as the quality increases (Wald, 2002). The RASE index is expressed as follows:

$$RASE = \frac{100}{M} \sqrt{\frac{1}{N} \sum_{i=1}^{N} RMSE(B_i)^2} \qquad (5)$$

where M is the mean radiance of the N spectral bands (B_i) of the original MS bands.

3. RESULTS

Figure 1 presents two subsets of the original image, panchromatic, Brovey, Ehlers and PCA fused sample images. Visual inspection showed that the Ehlers fused images have poor spatial details and blur near the edges are very obvious. The Brovey method provides nice images which present sharp details but close examination indicated that the dark areas became darker, and the white one whiter than the original images. The PCA method provides better enhanced fused images than the other methods.

The statistical measures on the difference between the original and synthesized images are presented in Table 2, 3. In the case of the Brovey method the statistical results remain of poor quality, low correlation coefficients in all bands reveals the weak similarities between the original image and fused images. The high and negative difference in variance in blue and NIR bands indicates that more Pan information has been introduced to synthesized images.

The Ehlers method also offers low correlation coefficients. This clearly indicates the weak similarities between the actual images and the synthesized ones. The high and positive difference in variance in blue, green and red bands, expresses the information lost in these bands during the enhancement of spatial resolution. The PCA method performs slightly better than the other methods. The highest correlation coefficient between the

synthesized images and the original one in all bands denotes good similarities in small structures. Thus, the PCA method produces less error in blue, green, red and NIR bands.

	Band 1	Band 2	Band 3	Band 4
Brovey	0.61	0.64	0.64	0.62
PCA	0.96	0.97	0.97	0.84
Ehlers	0.66	0.65	0.65	0.70

Table 2. Correlation coefficients between the original and fused QuickBird images.

	Band 1	Band 2	Band 3	Band 4
Brovey	-12%	8%	20%	-70%
PCA	-6%	6%	16%	-4%
Ehlers	23%	34%	44%	-6%

Table 3. Difference in variance relative to the actual variance.

The PCA method presented the lowest value of the RASE and the ERGAS index. Hence, the spectral quality of images fused by the PCA method is much better than the others. In contrast, the Ehlers method has highest values for the both RASE and ERGAS indices. Table 4 compares the obtained results.

	RASE (%)	ERGAS
Brovey	14.39	3.58
Ehlers	14.66	3.74
PCA	9.34	2.37

Table 4. The global errors for each method

4. DISCUSSION

The Brovey method can achieve higher spatial results but preserve less spectral fidelity. Because the Brovey method uses a ratio technique and changes the DN values a lot. The Brovey method place much more emphasis on the spatial information than the spectral information. The Ehlers method also distorted the spectral characteristics of the data one possible reason could be because the intensity component is not similar to the Pan. Moreover the intensity image can be different depending on the QuickBird band combination used in Ehlers transformation. The PCA method distorted the spectral characteristics of the data the least. The PCA method can combine the Pan with all the QuickBird bands at the same time. This indicates the assumption that the Pan data are similar to the first principal component is acceptable.

5. CONCLUSIONS AND PROSPECT

5.1 Conclusions

The visual analysis of the fused images indicates the results generated with PCA method preserves spectral and spatial information of the objects in original images better than the results generated by either the Brovey or Ehlers methods. The statistical comparison of the PCA with the Brovey and Ehlers shows that the PCA fused image has the best spectral fidelity. Therefore it is the best method for QuickBird image fusion in the three algorithms.

5.2 Prospect

In order to find the suited fusion algorithm for individual tree crown identification, this study selected the PCA, Brovey and Ehlers methods. To discover the best method more fusion methods should be tested in future.

In this study a few common statistical evaluation criteria were selected. For future research to assess fusion results comprehensively more statistical indexes should be evaluated. Also other approaches for quality assessment of fused images, such as comparison of crown maps obtained from individual tree crown identification, warrant future investigation.

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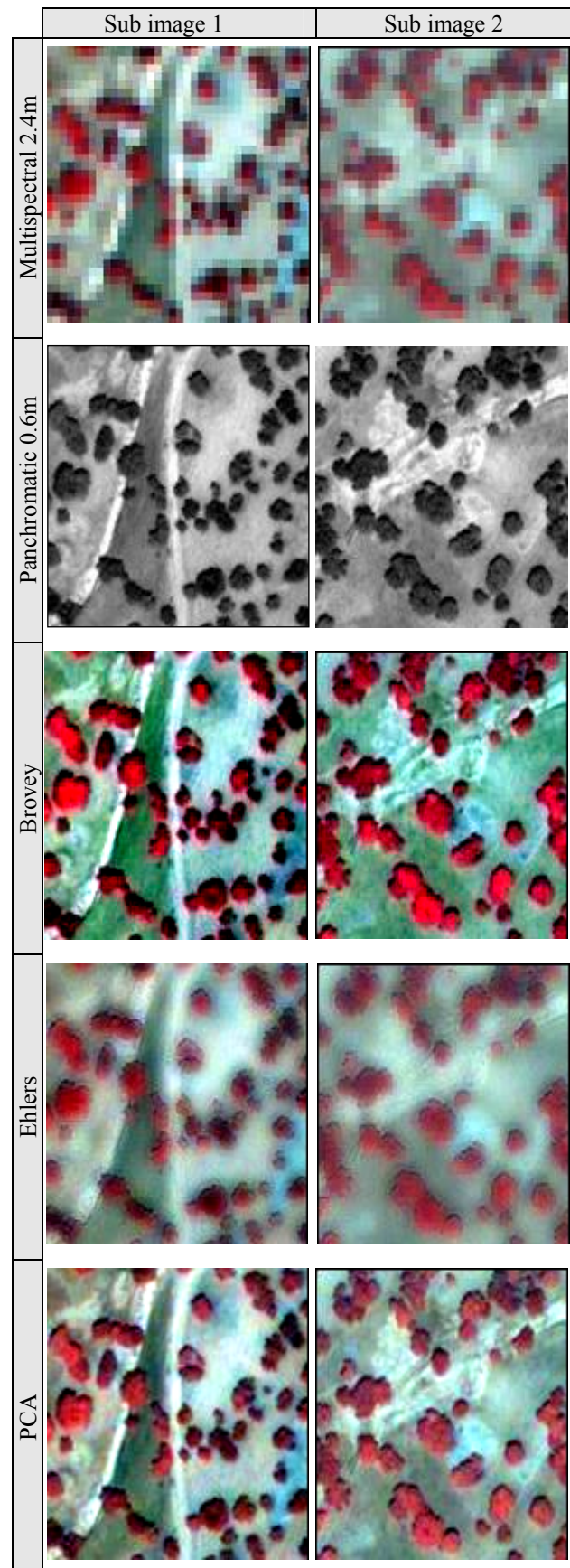
Figure 1 Example of colour composites (R.G. B. = 4, 3, 2) of the fused sub images versus panchromatic and original multispectral sub images