

A New Intensity-Hue-Saturation Based Method for Fusing High Resolution Satellite Images

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Abstract

Among various image fusion techniques, the intensity-hue-saturation (IHS) based methods are widely used in many commercial software packages to merge high spatial resolution Panchromatic (PAN) images with high spectral resolution multispectral (MS) images. Several downsides are inherent with IHS-based fusion methods such as significant color distortions, low spatial quality and complicated computations especially when merging large volumes of Ikonos or QuickBird images. This paper introduces a new IHS-based fusion method to overcome these downsides. In the proposed method a spectrally adjusted intensity (I) image derived by introducing weighting and tradeoff parameters to all the MS bands was used. The weighting parameters were assigned according to the intersection area between the spectral response curve of each MS band and that of the PAN image. The tradeoff parameter was then used with different values to control the tradeoff between the spatial and spectral information of the images to be fused. The proposed method was applied to merge PAN and MS images of QuickBird and Ikonos covering different features of Tanta and Alexandria cities in Egypt. The fused images resulted by the new method were compared visually and statistically to the original PAN and MS images as well as to those resulted by other existing IHS-based fusion methods. In addition to its fast and simple implementation, the proposed method has proved its capability to provide more accurate fused images better than the other existing IHS-based fusion methods, both spatially and spectrally.

1. Introduction

Fusion of high spatial resolution panchromatic (PAN) images with high spectral resolution multispectral (MS) images is a powerful tool for many remote sensing applications such as land-cover classification, change detection, and mapping of urban areas. The merged image is a product that synergistically combines the spatial and spectral information from the PAN and MS image respectively (Tu et al., 2004). Generally, many image fusion techniques have been developed for scientific applications (Wald et al., 1997, Pohl and Van Genderen, 1998, Ranchin and Wald, 2000, Tu et al., 2001, Zhang, 2002, Svab and Ostir, 2006 and Ehlers et al., 2010). In particular, intensity-hue-saturation (IHS) method is probably the most commonly used fusion technique in remote sensing community. IHS fusion method largely explains the popularity of perceptual color space and overcomes the commonly used red, green and blue (RGB) color space drawbacks, which does not relate intuitively to the attribute of human color perception. It has been implemented as a standard procedure to perform image fusion in many image processing software packages (Carper et al., 1990 and Chavez

et al., 1991). In IHS fusion method, the MS image is converted from RGB color space into the IHS color space. Then because the intensity component I, being related to the spatial information, is highly resembles the PAN image, it is replaced by the PAN image to inject the high spatial details of the PAN image into the original MS image. Next a reverse transformation from IHS to RGB is performed on the PAN image together with the hue (H) and saturation (S) bands resulting in an IHS fused image (Zhang, 2004). Practically, three downsides are inherent in the direct implementation of IHS fusion; (1) It can be only used to fuse three bands of the MS image and consequently for QuickBird and Ikonos images the near infrared (NIR) band is not involved in the fusion process. (2) It is computationally intensive and requires numerous mathematical operations for color transformation especially for large images from high resolution satellites (QuickBird and Ikonos). (3) Significant color distortion usually appears in the fused images as a result of the low correlation between the I component and the PAN image, that is the PAN and I images are spectrally dissimilar (Zhang, 2004).

To reduce the computation complexity of IHS fusion, Tu et al., (2001) introduced a fast implementation procedure for IHS method (FIHS) in which the fused bands can be easily obtained by adding the difference image between the PAN and I images to the original MS bands. The FIHS not only reduces the mathematical operations of traditional IHS method, but also extends its three order color transformation to include all the bands of the MS image. However, the FIHS produces the same spectral distortions in the fused images as the typical IHS method. To overcome the color distortion problem and to improve the spectral quality of the fused images resulted using either IHS or FIHS fusion technique, the following existing approaches have been proposed:

- Considering the NIR band in the definition of the intensity image using the FIHS fusion technique.
- Using a modified I image that is spectrally adjusted by introducing different weighting parameters to some of or all the MS bands, (IHS+SA₁) and (IHS+SA₂).
- Applying a constant tradeoff parameter for all the MS bands (IHS+TP) to control the tradeoff between the spatial and spectral resolutions of the image to be fused.
- Using a hybrid algorithm based on IHS and multiresolution wavelet decomposition (IHS+W) to extract the high frequency components from the PAN image and then inject them into the I image.

This paper introduces a new fusion technique that can overcome all downsides inherent in IHS fusion aiming to obtain higher spatial and spectral qualities than existing approaches. In the proposed technique a spectrally adjusted intensity image was determined using different weighting parameters to all MS bands. The weighting parameters were defined according to the intersection area of the spectral response pattern of each band with that of the PAN image. Then a tradeoff parameter was applied to control the spatial and spectral accuracy of the fused images. The proposed method was examined to merge PAN and MS data sets of QuickBird and Ikonos images covering agricultural and urban areas in Tanta and Alexandria cities, Egypt. The resulted fused images using the proposed method were compared visually and statistically to the original

PAN and MS images and also to the fused images obtained using other existing IHS-based fusion methods.

2. Study Sites and Data Sets

Two data sets of each of QuickBird and Ikonos satellites were used. Each data set comprises a PAN image and a MS image. The first QuickBird set acquired on September 3, 2010 covers an agricultural area in Tanta city, El-Gharbiya, Egypt. The second QuickBird set acquired on May 6, 2007 covers a city area with different urban features in Alexandria, Egypt as shown in figures 1 and 2. Each QuickBird PAN image is 1024 pixels by 1024 pixels with a pixel size of 0.6 m and each QuickBird MS image is 256 pixels by 256 pixels with a pixel size of 2.4 m. The first Ikonos set was acquired on August 22, 2009 covering another agricultural area in Tanta city. The second Ikonos set was acquired on March 16, 2011 covering the same area as that of the second set of QuickBird in Alexandria as shown in figures 3 and 4. Each Ikonos PAN image is 616 pixels by 616 pixels with a pixel size of 1.0 m and each Ikonos MS image is 154 pixels by 154 pixels with a pixel size of 4.0 m. For each set, the MS image was geometrically registered to its corresponding PAN image using the second order polynomial and the nearest neighbor resampling technique. The accuracy of the registration process is less than half a pixel for each data set.

3. IHS-Based Fusion Methods

These methods are mainly based on the transformation of RGB color space to IHS color space that offers the advantage of outlining different color properties in separate components.

3.1 Typical IHS and Fast IHS (FIHS)

Fusion Methods

The IHS fusion for each pixel can be formulated as follows:

$$\begin{bmatrix} I \\ v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$H = \tan^{-1}(v_2/v_1), \text{ and } S = \sqrt{v_1^2 + v_2^2}$$

Equation 1

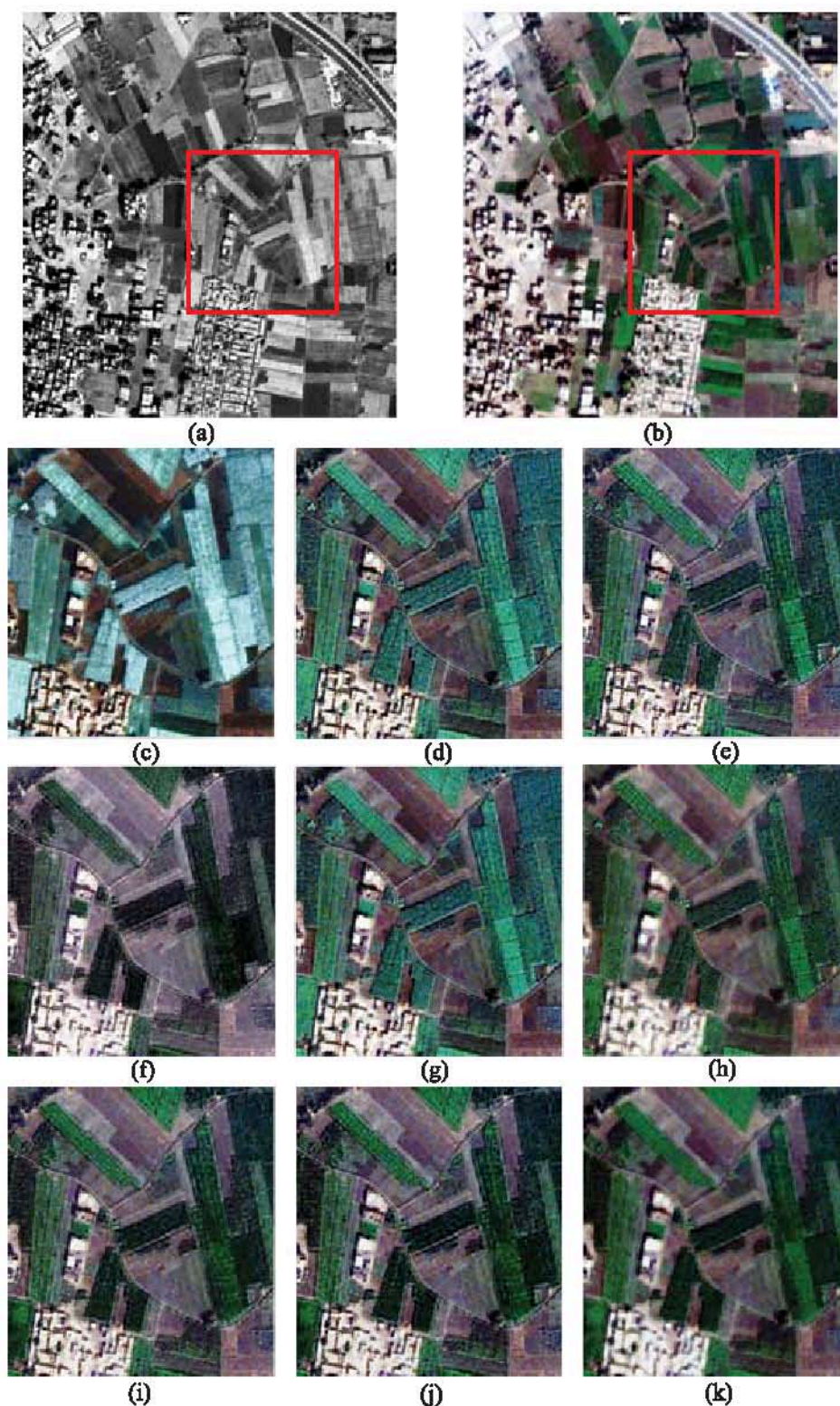


Figure 1: Original images and results of fusion methods for QuickBird Tanta site. (a) Original PAN, (b) Original MS, (c) IHS, (d) FIHS, (e) IHS+SA₁, (f) IHS+SA₂, (g) IHS+TP, (h) IHS+W, (i) IHS+Area, (j) IHS+Area (TP=0.8), (k) IHS+Area (TP=0.4)

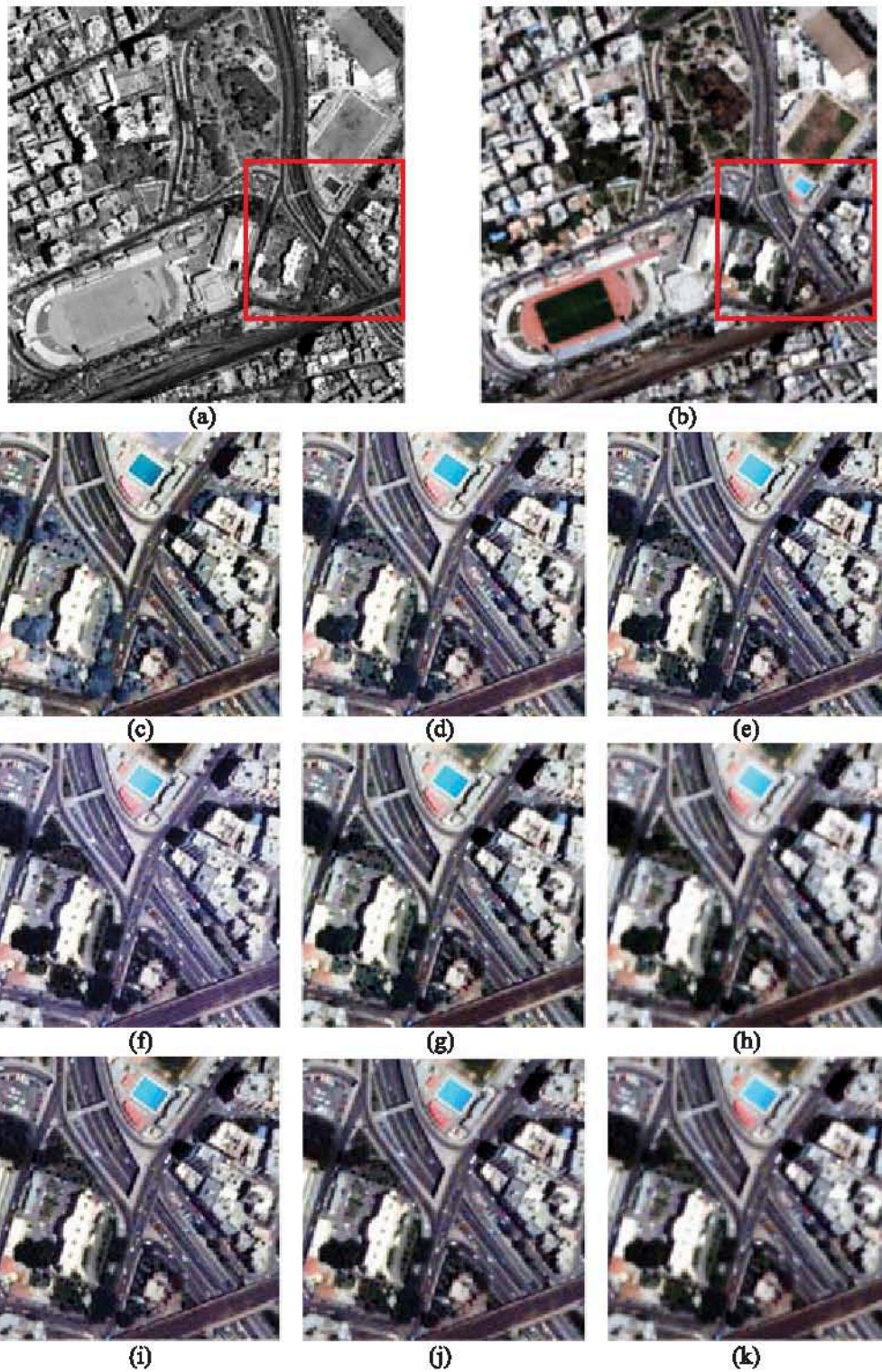


Figure 2: Original images and results of fusion methods for QuickBird Alexandria site. (a) Original PAN, (b) Original MS, (c) IHS, (d) FIHS, (e) IHS+SA₁, (f) IHS+SA₂, (g) IHS+TP, (h) IHS+W, (i) IHS+Area, (j) IHS+Area (TP=0.8), (k) IHS+Area (TP=0.4)

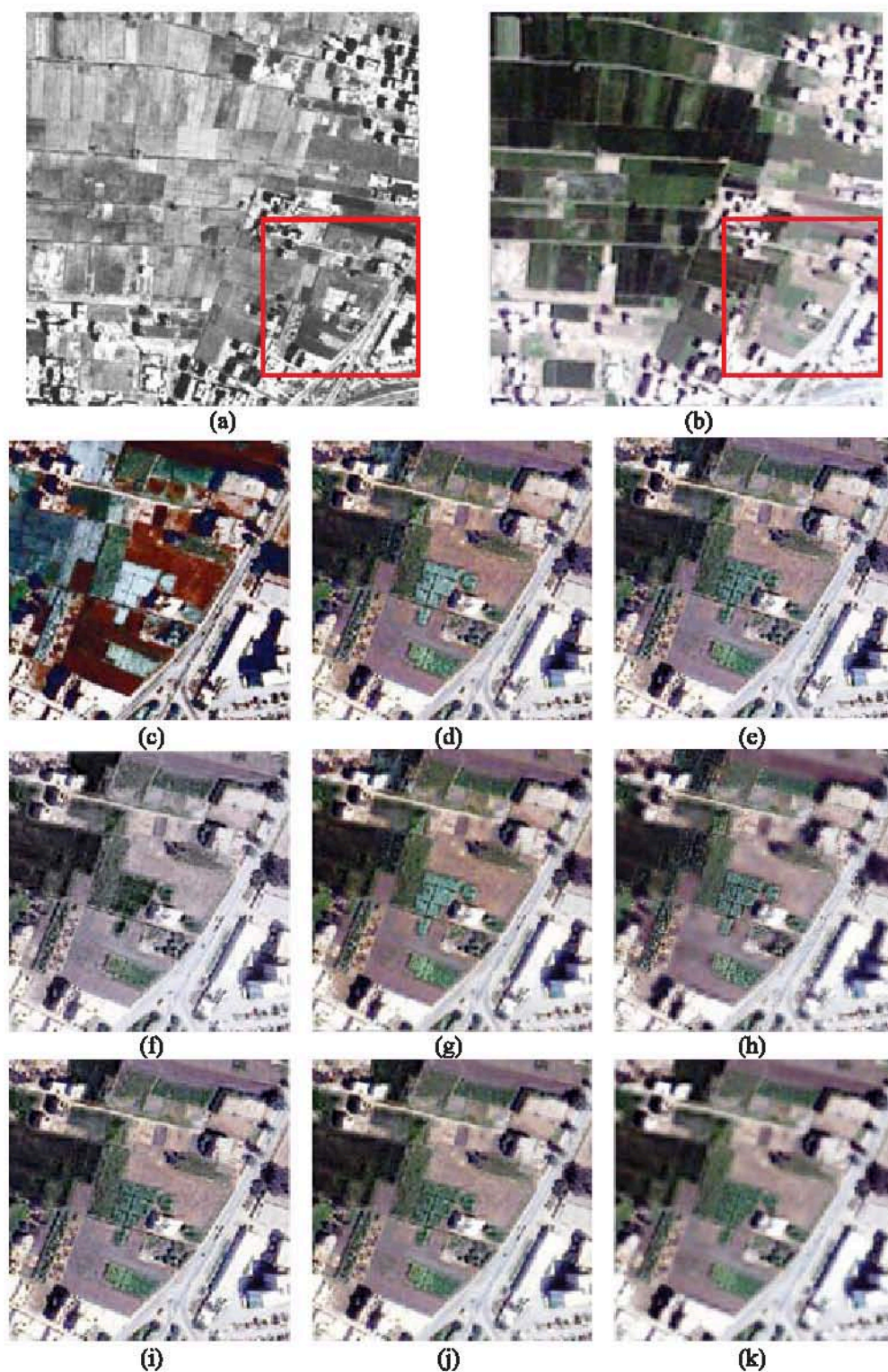


Figure 3: Original images and results of fusion methods for Ikonos Tanta site. (a) Original PAN, (b) Original MS, (c) IHS, (d) FIHS, (e) IHS+SA₁, (f) IHS+SA₂, (g) IHS+TP, (h) IHS+W, (i) IHS+Area, (j) IHS+Area (TP=0.8), (k) IHS+Area (TP=0.4)

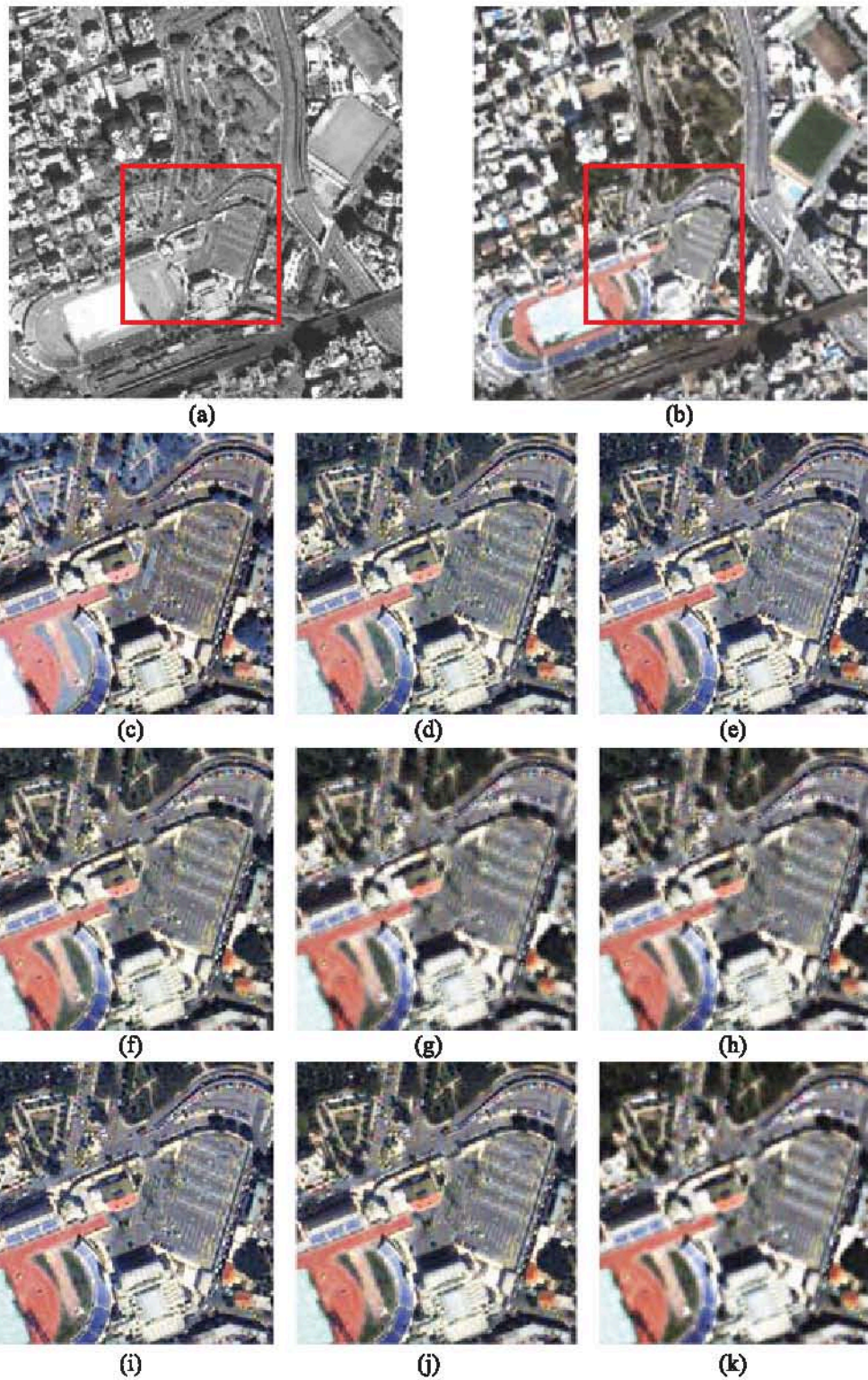


Figure 4: Original images and results of fusion methods for Ikonos Alexandria site. (a) Original PAN, (b) Original MS, (c) IHS, (d) FIHS, (e) IHS+SA₁, (f) IHS+SA₂, (g) IHS+TP, (h) IHS+W, (i) IHS+Area, (j) IHS+Area (TP=0.8), (k) IHS+Area (TP=0.4)

The intensity component is then replaced by the PAN image and the composition (PAN, H, and S) is transformed back into RGB color space (Firouz et al., 2011). To reduce the multiplication and addition operations, a FIHS fusion procedure can be implemented according to equation (2):

$$\begin{aligned} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} &= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} \text{PAN} \\ v_1 \\ v_2 \end{bmatrix} \\ \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} &= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I + (\text{PAN} - I) \\ v_1 \\ v_2 \end{bmatrix} \\ \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} &= \begin{bmatrix} R + (\text{PAN} - I) \\ G + (\text{PAN} - I) \\ B + (\text{PAN} - I) \end{bmatrix} = \begin{bmatrix} R + \delta \\ G + \delta \\ B + \delta \end{bmatrix} \end{aligned} \quad \text{Equation 2}$$

Where,

R', G', B' are the fused images.
 $\delta = (\text{PAN} - I)$

Equation (2) states that the fused images $[R', G', B']^T$ can be easily obtained from the original image $[R, G, B]^T$ by using addition operations. The large value of the difference (δ) between PAN and I images produces significant color distortions in the fused images. In spite of the PAN image is matched to the I component before replacing it, the two images are spectrally dissimilar and have not the same radiometry. Based on equation (2), the FIHS method can be extended to include the NIR band in the definition of I component as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ \text{NIR}' \end{bmatrix} = \begin{bmatrix} R + (\text{PAN} - I_1) \\ G + (\text{PAN} - I_1) \\ B + (\text{PAN} - I_1) \\ \text{NIR} + (\text{PAN} - I_1) \end{bmatrix} \quad \text{Equation 3}$$

Where: $I_1 = (R + G + B + \text{NIR})/4$

Equation 4

3.2 IHS with Spectral Adjustment (IHS+SA)

Fusion Methods

Equation (4) stated that in FIHS all the MS bands are equally considered to derive the new intensity component. However for IHS with spectral adjustment methods, different weighting parameters are used to assign the contribution of different MS bands in the derived I image. These methods take into account that the spectral response curve of the PAN band does not completely cover the MS bands. As shown in figure (5), the spectral response curves are similar for QuickBird and Ikonos; the PAN band extends from visible to NIR bands. Its sensitivity is slightly low in green and very low in blue. Tu et al., (2004) proposed the first model of IHS with spectral adjustment (IHS+SA₁) based on FIHS procedure using only two different weighting parameters introduced to the green and blue bands. The (IHS+SA₁) can be formulated as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ \text{NIR}' \end{bmatrix} = \begin{bmatrix} R + (\text{PAN} - I_{\text{mod}}) \\ G + (\text{PAN} - I_{\text{mod}}) \\ B + (\text{PAN} - I_{\text{mod}}) \\ \text{NIR} + (\text{PAN} - I_{\text{mod}}) \end{bmatrix}$$

Equation 5

$$I_{\text{mod}} = (R + 0.75G + 0.25B + \text{NIR})/3$$

Equation 6

It was stated that the values of these parameters were estimated experimentally after the fusion of 92 Ikonos images covering different areas (Tu et al., 2004). Similarly, the second model of IHS with spectral adjustment (IHS+SA₂) was developed using the weighting parameters but for all the multispectral bands. The modified I image for (IHS+SA₂) is as follows:

$$I_{\text{mod}} = (0.3R + 0.75G + 0.25B + 1.7\text{NIR})/3 \quad \text{Equation 7}$$

The weighting parameters of (IHS+SA₂) in equation (7) were also determined experimentally after fusing 29 images.

3.3 IHS with Tradeoff Parameter (IHS+TP)

Fusion Method

Choi, (2006) proposed the IHS with tradeoff parameter (IHS+TP) based also on FIHS.

The tradeoff parameter was used to control the tradeoff between the spatial and spectral resolutions of the fused image. It can be expressed as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + t(PAN - I_1) \\ G + t(PAN - I_1) \\ B + t(PAN - I_1) \\ NIR + t(PAN - I_1) \end{bmatrix}$$

Equation 8

t = a tradeoff parameter in the interval $[0, 1]$
 $I_1 = (R + G + B + NIR)/4$

Choi, (2006) used a value of 0.8 as a well-suited tradeoff parameter to merge Ikonos images. Due to the similarity of the spectral response ranges of corresponding bands for Ikonos and QuickBird, the same value was considered as an appropriate tradeoff parameter to fuse QuickBird images (Afify, 2012).

3.4 IHS with Wavelet (IHS + W) Fusion Methods

Gonzalez et al., (2004) introduced the IHS with wavelet (IHS+W) method. Multiresolution wavelet decomposition is used to separate the spectral content of an image from the spatial content. In this hybrid algorithm, wavelet transform was used to extract the spatial information of the PAN image. Then the IHS procedure was applied to inject these spatial details into the I image. (IHS+W) method can be implemented based also on FIHS as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + \sum_{i=1}^n W_{pan} \\ G + \sum_{i=1}^n W_{pan} \\ B + \sum_{i=1}^n W_{pan} \\ NIR + \sum_{i=1}^n W_{pan} \end{bmatrix}$$

Equation 9

Where, $\sum_{i=1}^n W_{pan}$ = the sum of high frequency versions (n) of the wavelet-transformed PAN image. The wavelet approach preserves the spectral characteristics of the MS image better than the IHS

method. However, images fused by wavelets have much less spatial information than those fused by IHS method (Choi, 2006). In this study Mallat wavelet model (Gonzalez et al., 2004 and Amolins et al., 2007) was used with additive injection procedure where the detail images of PAN image were added to those of I component.

3.5 The Proposed Method

The new proposed fusion method is based also on FIHS and utilizes both the weighting and tradeoff parameters for all MS bands. The measured energy in an individual channel is sum (integral) of incoming radiation and relative spectral sensitivity. In ideal condition, all spectral bands would be well separated and would cover exactly the same wavelength range of the PAN band as shown in figure (5-c). In this case it is theoretically possible to obtain the values in the PAN band with the summation of respective spectral bands (Svab and Ostir, 2006). Since neither QuickBird nor Ikonos sensor shows such an ideal situation, adequate weighting parameters are required to assign the contribution of each MS band in the derived I component as follows:

$$I_{new} = W_B (B) + W_G (G) + W_R (R) + W_{NIR} (NIR)$$

Equation 10

In the proposed method, the weighting parameters were determined according to the intersection area between the spectral response curve of each MS band and that of the PAN band. The weighting parameter for a certain MS band was assigned as the ratio between the intersection area of that band to the sum of intersection areas of all MS bands. It was estimated, for example, for the blue band as follows:

$$W_B = \frac{A_B}{A_B + A_G + A_R + A_{NIR}}$$

Equation 11

W_B = the weighting parameter for the blue band.

A_B = the intersection area between the spectral response curve of blue and PAN bands as shown in figure (5).

A_B, A_G, A_R, A_{NIR} = the intersection areas between each of B, G, R, and NIR bands and PAN band.

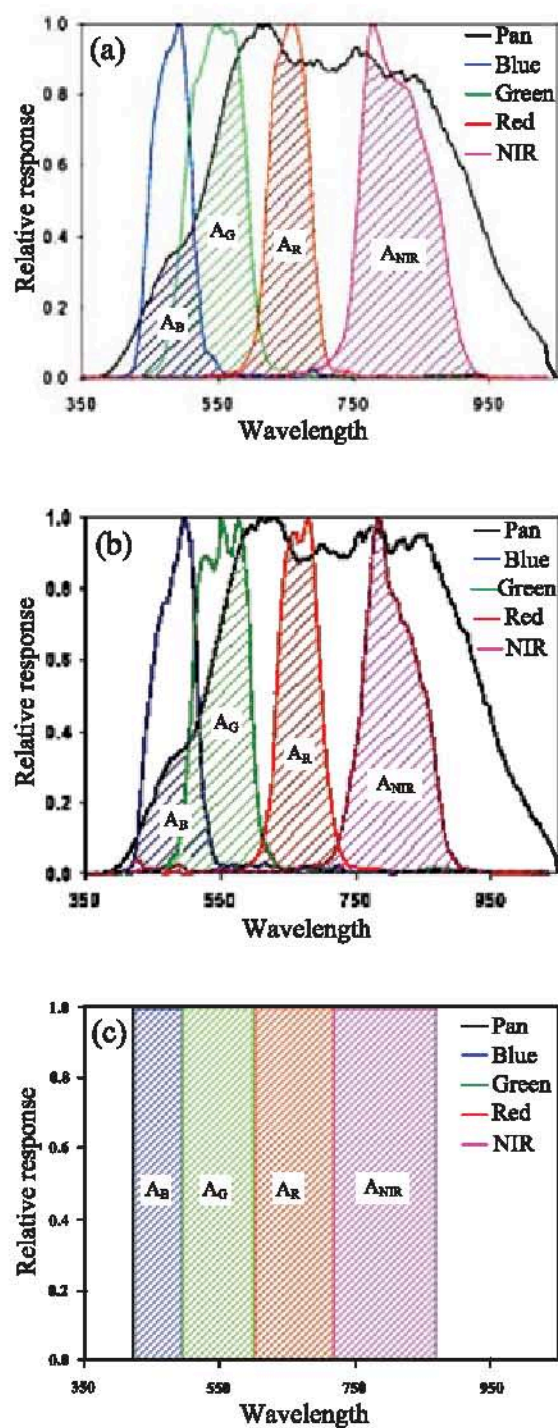


Figure 5: Spectral response curves of (a) QuickBird, (b) Ikonos, and (c) Ideal sensor

After determining the intersection areas between the spectral response curves of each of the B, G, R, and NIR bands and the PAN band, the weighting parameters for all the bands of QuickBird and Ikonos were determined and provided in equations (13) and (14). An appropriate tradeoff parameter in the interval [0, 1] was then used to improve the spectral characteristics of the fused images. Hence, the proposed fusion method can be expressed as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + t.(PAN - I_{new}) \\ G + t.(PAN - I_{new}) \\ B + t.(PAN - I_{new}) \\ NIR + t.(PAN - I_{new}) \end{bmatrix}$$

Equation 12

Where,

$I_{new} = 0.111 (B) + 0.264 (G) + 0.237 (R) + 0.388 (NIR)$
for QuickBird images.

Equation 13

$I_{new} = 0.130 (B) + 0.268 (G) + 0.254 (R) + 0.348 (NIR)$
for Ikonos images.

Equation 14

4. Experiments and Results

Six existing IHS-based fusion methods in addition to the new proposed method were applied to merge the four data sets of QuickBird and Ikonos images. These methods are:

- 1- Traditional IHS (IHS).
- 2- Fast IHS (FIHS) which includes the NIR band in the definition of I band.
- 3- Two methods of IHS with spectral adjustment (IHS+SA_{1,2}).
- 4- IHS with a tradeoff parameter (IHS+TP).
- 5- IHS with wavelet transform (IHS+W) method.
- 6- The new proposed method which will be referred as Area model (IHS+Area).

For each data set, the MS image was up sampled using cubic interpolation so that the pixel size equals that of its corresponding PAN image. Then different fusion techniques were applied. Figures 1 and 2 show the fused images for the two data sets of QuickBird and figures (3) and (4) show the fused images for the two data sets of Ikonos. Concerning the proposed method (IHS+Area), it was applied

according to the weighting parameters of equations (13) and (14), and using different tradeoff parameters ranging from 1.0 to 0.2 with a decreasing increment value of 0.2 at each time. If (t=0) the fused images are exactly similar to the original MS images with no spectral distortion but theoretically with the lowest spatial resolution. If (t=1) the fused images are exactly similar to those resulted using FIHS with significant spectral distortion but may have a high spatial resolution.

5. Quantitative Accuracy Assessments

To statistically evaluate the spectral quality of the fused images, they were first degraded to their original spatial resolution (2.4 m for QuickBird and 4.0 m for Ikonos) using cubic resampling, and then compared to the original MS bands by computing the following quantitative parameters:

- 1- The correlation coefficients (CCs) between the fused images and the original MS images;

$$CC(A/B) = \frac{\sum_{i=1}^n (A_i - \bar{A})(B_i - \bar{B})}{\sqrt{(\sum_{i=1}^n (A_i - \bar{A})^2)(\sum_{i=1}^n (B_i - \bar{B})^2)}}$$

Equation 15

Where,

A_i and B_i = the pixel brightness values of the original and fused images.

\bar{A} and \bar{B} = the mean brightness values of the original and fused images.

n = number of pixels.

- 2- ERGAS (Erreur Relative Globale Adimensionnelle de Synthèse) is a simplified quantity that summarizes the errors in all bands. The lower the ERGAS value, the better the spectral quality of the fused images. The ERGAS index for the fusion is expressed as follows:

$$ERGAS = 100 \frac{h}{l} \sqrt{\frac{1}{N} \sum_{k=1}^N \frac{RMSE^2(A_k)}{\bar{A}_k^2}}$$

Equation 16

Where,

h = the resolution of the high spatial resolution image.

l = the resolution of the low spatial resolution image.

N = number of bands.

A_k = the mean values of the original band k .

$RMSE(A_k)$ = the root mean square error of band k that can be computed as follows:

$$RMSE(A_k) = \sqrt{\frac{\sum_{i=1}^n (A_i - B_i)^2}{n}}$$

Equation 17

A_i and B_i = the pixel brightness values of original and fused images of band k .

n = number of pixels.

The correlation coefficients and ERGAS values are shown in table 1 for the four data sets of QuickBird and Ikonos images. To evaluate the spatial quality of the fused images, the PAN and fused images were filtered using the high pass Laplacian filter then the correlation coefficients between the filtered PAN and the filtered fused images were computed (Zhou et al., 1998). Table 1 shows the correlation coefficients between the filtered PAN and the filtered fused images obtained by different fusion methods for the four data sets. In table 1 the correlation coefficients of the six existing fusion methods are shown in column 2 to column 7 while the last three columns show the correlation coefficients due to using the proposed area model with only three values of TP (1.0, 0.8, and 0.4). These TP values were chosen to enable the comparison between the new method and the existing methods

6. Analysis of Results

From table 1, it can be noted that the traditional IHS provided the least spectral quality especially for the blue band. The main reason for this significant color distortion is the differences in the spectral response curves between the PAN band and the MS bands. For both QuickBird and Ikonos sensors, the spectral response curve of the PAN band poorly covers that of the blue band and also with extremely low sensitivity. Visually the color distortions are clear especially in vegetation areas, as shown in figures (1 to 4). Comparing the results of the existing fusion methods (column 2 to column 7) for each data set, it can be noticed that the IHS with spectral adjustment (IHS+SA₁) method has provided the highest spatial accuracy. However, the proposed area model (IHS+Area) with TP = 1.0 has provided a spatial

accuracy that is superior to that obtained using (IHS+SA₁). Meanwhile, the spectral accuracy of the (IHS+Area) is also higher than that of the (IHS+SA₁). This means that for a certain application if the priority is to the spatial quality of the fused images, the proposed method has to be used to provide the highest spatial accuracy among all applied fusion methods and also to produce a spectral quality that is higher than that of (IHS+SA₁) fusion method. Using a tradeoff parameter with area model improved the spectral quality of the fused images but on the expense of their spatial quality. However, the value of the tradeoff parameter is inversely proportional to the values of the spectral correlation coefficients and directly proportional to the values of the spatial correlation coefficients. For QuickBird and Ikonos Tanta agricultural study area, the (IHS+Area) with TP = 0.8 has provided spectral and spatial accuracies higher than those obtained using (IHS+TP) method. In urban study area of Alexandria, the spectral quality of (IHS+Area) with TP = 0.8 is slightly lower than that of (IHS+TP) but the spatial quality of (IHS+Area) with TP = 0.8 is higher than that of (IHS+TP). It seems that for (IHS+Area) method, a TP less than 0.8 is required for Alexandria scenes to improve its spectral quality without much deterioration to its spatial accuracy. Among the used existing fusion methods, the IHS with wavelet transform (IHS+W) has provided the highest spectral quality but the least spatial quality. This result was achieved and confirmed in several previous scientific papers (Gonzalez et al., 2004, Amolins et al., 2007 and Affy, 2012). However, the proposed (IHS+Area) with TP = 0.4 has provided a spectral accuracy that is higher than that obtained using (IHS+W) method. In addition, the spatial accuracy of the (IHS+Area) with TP = 0.4 is considerably higher and more satisfactory than that obtained using the (IHS+W), especially in agricultural areas of Tanta study site. Therefore, for a certain application if the spectral accuracy has the priority, the (IHS+Area) with TP = 0.4 or less has to be applied to provide the highest spectral accuracy among all applied fusion methods and also with a spatial quality that is higher than that obtained using IHS with wavelet transform fusion method. The visual inspection of the fused images using different methods confirmed the statistical analyses where the colors of different features are very similar to the original MS bands when the proposed area model (IHS+Area) with TP = 0.4 was used.

Table 1: Correlation coefficients of the study sites. (a) QuickBird Tanta, (b) QuickBird Alex, (c) Ikonos Tanta, (d) Ikonos Alex

	CCs	Existing fusion methods						New proposed fusion method		
		IHS	FIHS	IHS+SA ₁	IHS+SA ₂	IHS+TP	IHS+W	IHS+Area TP = (1.0)	IHS+Area TP = (0.8)	IHS+Area TP = (0.4)
QuickBird Tanta	R/R'	0.8057	0.9396	0.9381	0.9330	0.9618	0.9842	0.9419	0.9620	0.9901
	G/G'	0.6884	0.8838	0.8834	0.8758	0.9257	0.9707	0.8920	0.9282	0.9810
	B/B'	0.5345	0.8205	0.8226	0.8427	0.8835	0.9545	0.8435	0.8934	0.9708
	PAN/R'	0.9383	0.9560	0.9613	0.9300	0.9413	0.7927	0.9650	0.9538	0.8764
	PAN/G'	0.9394	0.9587	0.9614	0.9301	0.9479	0.7902	0.9660	0.9577	0.9019
	PAN/B'	0.9281	0.9551	0.9592	0.9187	0.9442	0.7830	0.9607	0.9484	0.8992
	ERGAS	3.1149	1.7659	1.8468	2.5587	1.4128	0.9159	1.8270	1.3601	0.7217
QuickBird Alexandria	R/R'	0.8867	0.9436	0.9424	0.9361	0.9638	0.9893	0.9433	0.9632	0.9906
	G/G'	0.8854	0.9414	0.9392	0.9306	0.9613	0.9882	0.9397	0.9608	0.9900
	B/B'	0.7535	0.8645	0.8634	0.8583	0.9107	0.9825	0.8676	0.9113	0.9866
	PAN/R'	0.9712	0.9763	0.9772	0.9710	0.9733	0.8462	0.9804	0.9777	0.8893
	PAN/G'	0.9694	0.9759	0.9765	0.9687	0.9742	0.8477	0.9813	0.9789	0.8909
	PAN/B'	0.9672	0.9752	0.9757	0.9669	0.9726	0.8406	0.9778	0.9766	0.9184
	ERGAS	4.6231	3.3632	3.4188	3.8623	2.6879	1.3954	3.3533	2.6892	1.3494
Ikonos Tanta	R/R'	0.7712	0.9273	0.9330	0.9379	0.9538	0.9577	0.9377	0.9598	0.9900
	G/G'	0.6684	0.8850	0.8949	0.9065	0.9262	0.9348	0.9029	0.9367	0.9841
	B/B'	0.5339	0.8270	0.8442	0.8749	0.8873	0.9037	0.8571	0.9051	0.9757
	PAN/R'	0.8712	0.9405	0.9671	0.9476	0.9382	0.8274	0.9675	0.9651	0.9284
	PAN/G'	0.8709	0.9410	0.9672	0.9484	0.9401	0.8270	0.9682	0.9671	0.9429
	PAN/B'	0.8696	0.9394	0.9649	0.9460	0.9394	0.8252	0.9661	0.9658	0.9520
	ERGAS	7.6035	4.2674	4.1446	4.8494	3.4155	3.3566	4.1301	3.3171	1.7010
Ikonos Alexandria	R/R'	0.8661	0.8958	0.8865	0.8888	0.9329	0.9668	0.8930	0.9312	0.9833
	G/G'	0.8219	0.8597	0.8481	0.8514	0.9088	0.9551	0.8561	0.9065	0.9772
	B/B'	0.6531	0.7213	0.7055	0.7261	0.8096	0.9063	0.7179	0.8065	0.9496
	PAN/R'	0.9845	0.9824	0.9855	0.9816	0.9799	0.9509	0.9862	0.9812	0.9493
	PAN/G'	0.9851	0.9828	0.9854	0.9821	0.9816	0.9520	0.9865	0.9826	0.9611
	PAN/B'	0.9842	0.9815	0.9843	0.9802	0.9817	0.9514	0.9846	0.9818	0.9740
	ERGAS	6.8898	5.6952	5.7926	5.8347	4.4893	3.1643	5.6284	4.5230	2.3650

Moreover, the small features like cars in Alexandria scenes and the edges in Tanta scenes are clearly visible with the highest degree of sharpness due to using the proposed area model (IHS+Area) with TP = 1.0 as shown in figures 1 through 4. The highest spatial and spectral qualities obtained due to using the new proposed method are referred to the consideration of the NIR in the definition of the I image, and to the validity and suitability of the weighing parameters values derived by the proposed

method to minimize the gray level differences between PAN and I images, and also to the use of an appropriate value of the tradeoff parameter. The computed values of ERGAS index for different fusion techniques indicated the same spectral quality obtained using the correlation coefficients where the higher the correlation coefficients between the fused images and their corresponding MS images, the smaller the ERGAS value. As a result, the smallest ERGAS values were generally obtained due to using

the proposed area model (IHS+Area) with TP= 0.4. For each data set of QuickBird and Ikonos, the obtained spatial quality due to applying a certain fusion method is always higher in Alexandria site (urban area) than in Tanta site (agricultural area). This can be attributed to the nature of the spatial details of different land cover classes in the area under consideration.

7. Conclusion

This paper presented a new IHS-based image fusion method that can overcome the downsides inherent in other IHS-based fusion methods. In the proposed method a spectrally adjusted intensity image derived by introducing weighting and tradeoff parameters to all the MS bands was used. The weighting parameters were determined according to the intersection area between the spectral response curve of each MS band and that of the PAN band. The tradeoff parameter was then used to control the tradeoff between the spatial and spectral resolution of the images to be fused. Among all the used fusion methods, the proposed method without a tradeoff parameter has provided the highest spatial accuracy of the fused images. It is followed by the IHS with spectral adjustment method (model 1). In addition, the spectral quality obtained by the proposed method without a tradeoff parameter is also higher than that obtained using the IHS with spectral adjustment method. Moreover, using the proposed method with a suitable tradeoff parameter has also produced the highest spectral quality followed by the IHS with wavelet transform method. In addition, the spatial quality obtained by the proposed method with a suitable tradeoff parameter is also higher than that obtained using the IHS with wavelet transform method. The highest spatial and spectral qualities obtained due to using the new method are referred to: (1) the consideration of the NIR band in the definition of the I image, (2) the validity and suitability of the weighing parameters values derived in the proposed method to produce an intensity image with a strong resemblance to the panchromatic image and (3) the choice of an appropriate tradeoff parameter. This study demonstrated that the proposed method can produce fused images with the superior spatial and spectral accuracies using the appropriate tradeoff parameter that can significantly preserve the spectral characteristics of the original MS images. Therefore, according to the purpose of each remote sensing application, an appropriate tradeoff parameter can be used to fulfill the application requirements for the spatial and spectral qualities.

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