# Intensity-Hue-Saturation Based Methods for Fusing QuickBird Images

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**Abstract**

*Several image fusion techniques are based on Intensity-Hue-Saturation (IHS) transformation. They are widely used to merge high spatial resolution Panchromatic (PAN) images with high spectral resolution multispectral (MS) images. Significant color distortions are expected when typical IHS technique is applied to merge Ikonos or QuickBird images. Some IHS-based techniques introduce weighting and tradeoff parameters to all the MS bands to spectrally adjust the intensity image. Others utilize the multiresolution wavelet decomposition algorithm to separate the spatial information of the PAN image and inject it to the intensity image. In this study the IHS-based fusion techniques are presented and applied to merge two data sets of QuickBird images covering agricultural and urban areas in Egypt. The purpose is to evaluate and compare the obtained spectral and spatial qualities of the fused images due to using different IHS-based fusion techniques. The fused images are compared visually and statistically to the original PAN and MS images. The results revealed that the IHS with wavelet addition method provided the highest spectral quality. However, the improvement of the spectral quality due to applying a certain method means the deterioration of the spatial quality and vise versa. Thus the selection of a certain IHS-based fusion technique depends mainly on the application requirements.*

## 1. Introduction

Earth observation satellites provide an increasing amount of images at different spatial, temporal, radiometric, and spectral resolutions. Recent remote sensing systems such as QuickBird and Ikonos generally provide PAN images at high spatial resolution and MS images at high spectral resolution but low spatial resolution. For example, QuickBird provides PAN images at 0.6 m ground resolution and MS images in four bands (blue, green, red, and near infrared) at 2.4 m ground resolution. Actually, due to sensor limitations and technical restrictions, the instruments are not capable of directly providing an image with high spatial and spectral resolutions. On the other hand, many remote sensing applications such as classification, change detection, feature recognition and mapping of urban areas require images that simultaneously have high spatial and high spectral resolutions. Hence, the most efficient and economic way to produce high spatial resolution multispectral images is by applying image fusion techniques to integrate the spatial details of a PAN image with the spectral information of a MS image. During the last two decades, several fusion techniques have been developed and reported in scientific papers (Wald et al., 1997, Pohl and Van Genderen, 1998, Ranchin and Wald, 2000, Zhang, 2002, Tu et al., 2002, Svab and Ostir, 2006 and Ehlers et al., 2010). However, IHS-based methods are the most widely used fusion techniques in commercial image processing systems. Unfortunately, one major downside of the traditional IHS fusion technique is that it can only be used to fuse three multispectral bands. Another downside is that if the correlation between the intensity component and the PAN image is low, color distortion is expected to appear in the fused images. To overcome the color distortion problem inherent in the typical IHS fusion technique, other IHS-based fusion techniques have been developed as follows:

- Using different weighing parameters introduced to all MS bands (blue, green, red, near infrared) to derive a new modified intensity image spectrally adjusted to the PAN image.
- Using a constant tradeoff parameter for all MS bands to control the tradeoff between the spatial and spectral resolutions of the image to be fused.
- Using a hybrid algorithm based on multiresolution wavelet decomposition and IHS to inject the high frequency components of PAN image into the intensity image.


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In this paper, different IHS-based fusion techniques are presented. The aim is to compare their performance to merge QuickBird PAN and MS images covering agricultural and urban areas in Egypt and to determine the effect of each on the spatial and spectral properties of the fused images. The resulted fused images are inspected visually and evaluated statistically to assess their spectral and spatial qualities. The processing steps of this study were performed by the aid of PCI, ENVI and ERDAS digital image processing systems.

**2. Study Sites and Data Sets**

Two data sets of QuickBird images were used. Each data set comprises a PAN image and a MS image. The first set was acquired on September 3, 2010 covering an agricultural area of Tanta city, El-Gharbiya, Egypt. The second set was acquired on May 6, 2007 covering a city area with different urban features of Alexandria, Egypt as shown in Figures 1 and 2. Each PAN image is 1024 pixels by 1024 pixels with a pixel size of 0.6 m and each MS image is 256 pixels by 256 pixels with a pixel size of 2.4 m. For each set, the MS image was registered to its corresponding PAN image using the second order polynomial and the nearest neighbor resembling technique. The accuracy of the registration process is less than half a pixel for both data sets.

**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 Fusion Method*

The typical IHS fusion method uses three low resolution MS bands and transforms them into IHS components as follows: (Firouz et al., 2011).

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

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

Equation 1

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

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

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R+\delta \\ G+\delta \\ B+\delta \end{bmatrix}$$

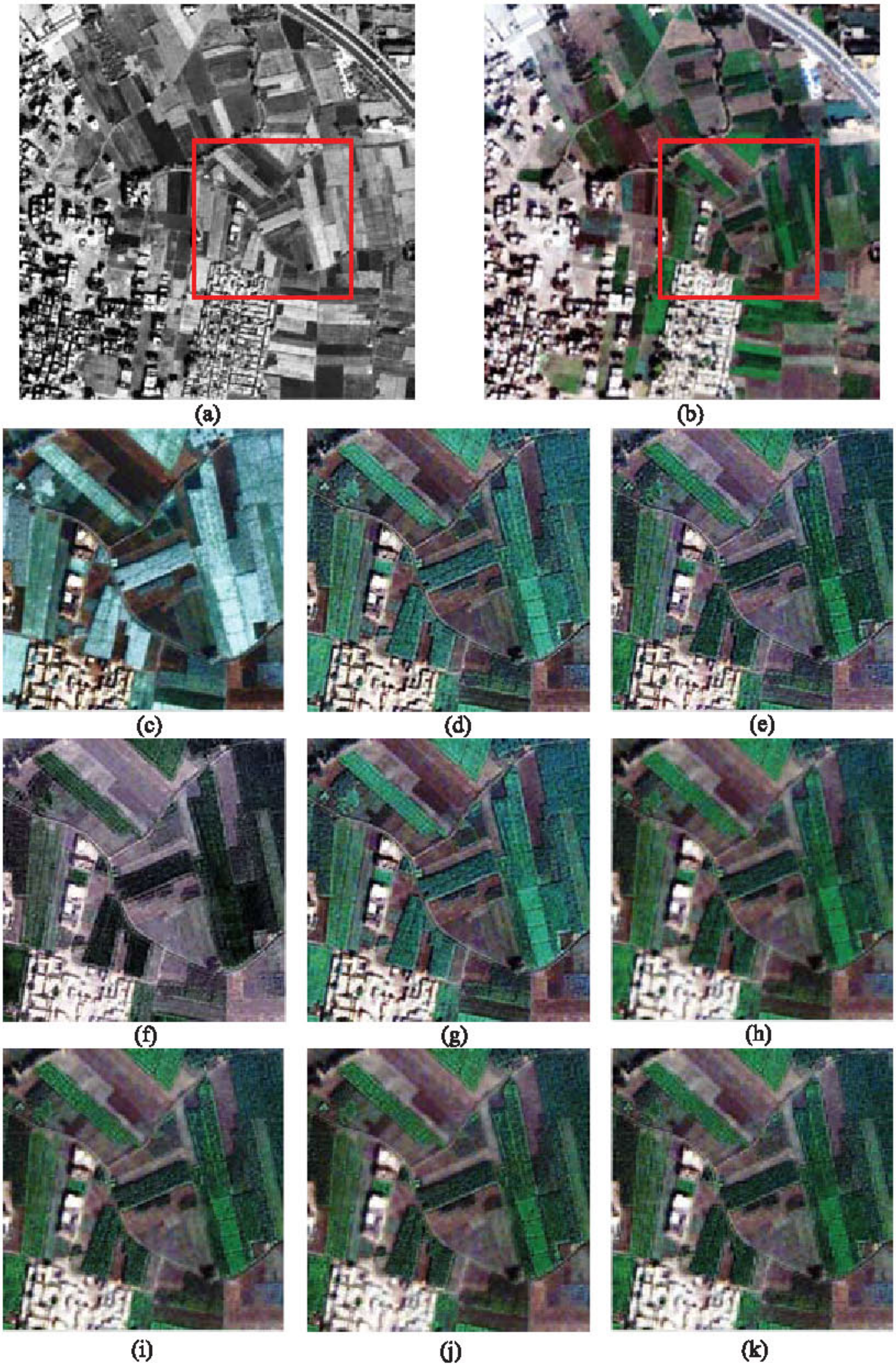
Equation 2

Where,

$R'$, $G'$, $B'$ are the fused images.

$\delta = (PAN - I)$

Equation (2) states that the fused images R', G', and B' can be easily obtained by adding the difference image between PAN and I to the original MS images. Generally, the difference (δ) is large for QuickBird images and therefore a color distortion problem in typical IHS fusion method is expected as a result of mismatches, that is the PAN and I images are spectrally dissimilar (Zhang, 2004).



(a) (b)

(c) (d) (e)

(f) (g) (h)

(i) (j) (k)

**Figure 1: Original images and results of fusion methods for Tanta site, (a) Original PAN, (b) Original MS, (c) IHS, (d) IHS+$SA_1$, (e) IHS+$SA_2$, (f) IHS+$SA_3$, (g) IHS+TP, (h) IHS+WAA, (i) IHS+WAS, (j) IHS+WMA, (k) IHS+WMS**

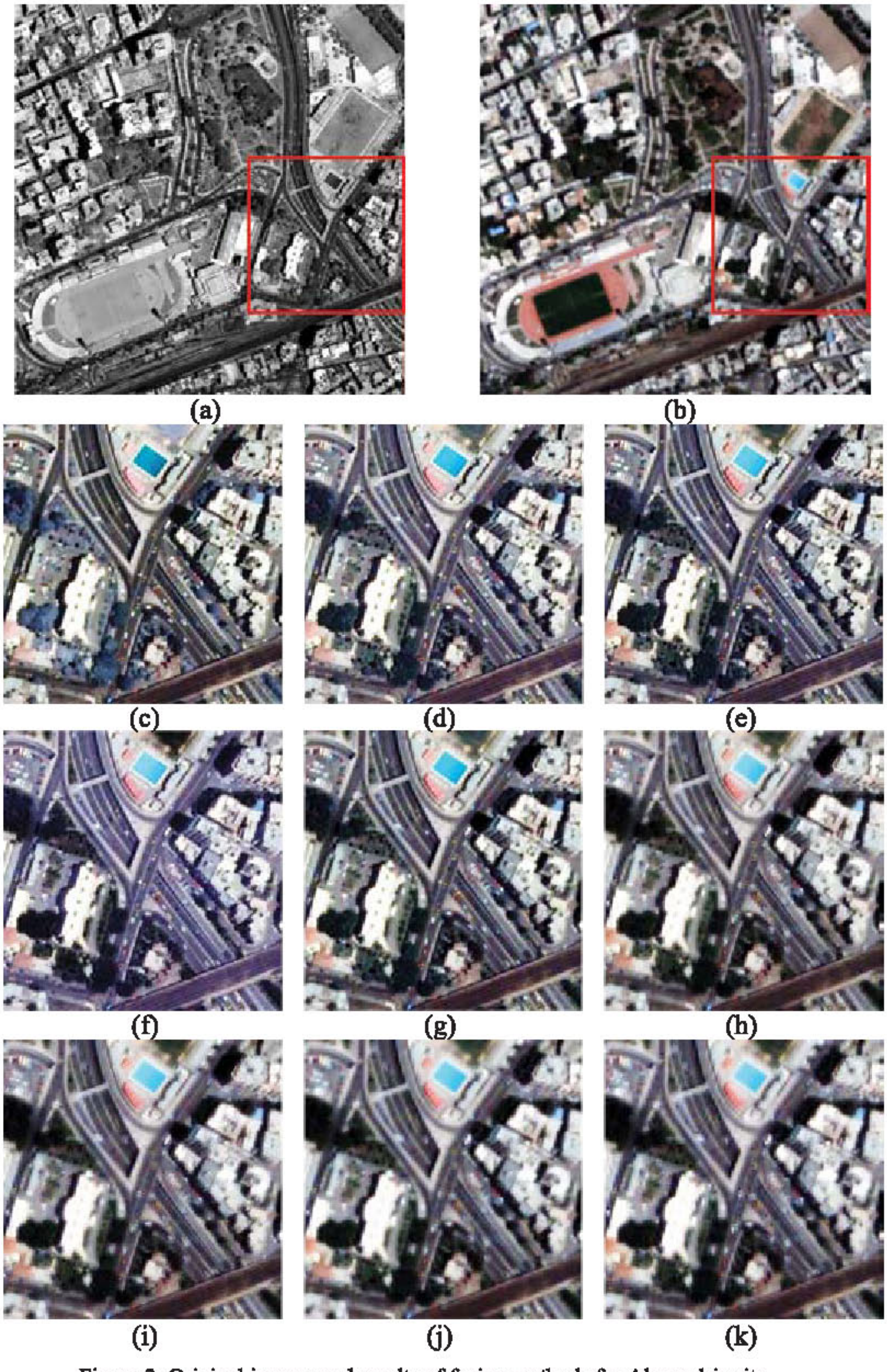


**Figure 2: Original images and results of fusion methods for Alexandria site, (a) Original PAN, (b) Original MS, (c) IHS, (d) IHS+$SA_1$, (e) IHS+$SA_2$, (f) IHS+$SA_3$, (g) IHS+TP, (h) IHS+WAA, (i) IHS+WAS, (j) IHS+WMA, (k) IHS+WMS**

*3.2 IHS with Spectral Adjustment (IHS+SA) Fusion Methods*

IHS with spectral adjustment (IHS+SA) fusion methods are based on the fast IHS procedure. They aim to derive a new modified intensity image I that minimizes the radiance difference (δ) between PAN and I images. The methods of this group have the advantage of including the NIR band in the definition of I component. They can be also extended traditional three-order transformation to any arbitrary order. The first method ($IHS+SA_1$) was developed by Tu et al., (2004). It can be formulated as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R+\delta_n \\ G+\delta_n \\ B+\delta_n \\ NIR+\delta_n \end{bmatrix}$$

Equation 3

Where,

$n = 1$ for the first method

$\delta_1 = (PAN - I_1)$

$$I_1 = (R + G + B + NIR)/4$$

Equation 4

In addition Tu et al., (2004) introduced the second method ($IHS+SA_2$) based also on the fast IHS procedure as in equation (3). This method takes into account that the spectral response of the PAN image does not completely cover that of the blue and green bands. So, different weighting parameters are used to assign the participation of the blue and green bands in the derived I component as follows:

$n = 2$ for the second method

$\delta_2 = (PAN - I_2)$

$$I_2 = (R + 0.75G + 0.25B + NIR)/3$$

Equation 5

Similarly, the third method ($IHS+SA_3$) was developed using the weighting parameters but for all the multispectral bands as follows:

$n = 3$ for the third method

$\delta_3 = (PAN - I_3)$

$$I_3 = (0.3R + 0.75G + 0.25B + 1.7NIR)/3$$

Equation 6

*3.3 IHS with Tradeoff Parameter (IHS +TP) Fusion Method*

This method was suggested by Choi, (2006) based also on fast IHS. The tradeoff parameter is used to control the tradeoff between the spatial and spectral resolutions of the image to be fused. It can be expressed as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R+t.\delta_1 \\ G+t.\delta_1 \\ B+t.\delta_1 \\ NIR+t.\delta_1 \end{bmatrix}$$

Equation 7

Where,

$t$ = a tradeoff parameter in the interval [0, 1]

$\delta_1 = (PAN - I_1)$

$I_1 = (R + G + B + NIR)/4$

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 for corresponding bands of Ikonos and QuickBird, the same value is considered as an appropriate tradeoff parameter to fuse QuickBird images in this study.

*3.4 IHS with Wavelet (IHS +W) Fusion Methods*

Multiresolution wavelet decomposition provides a powerful tool to separate the spectral content of an image from the spatial content. The wavelet transform model contains a bank of high and low pass filters which decomposes the input image into four images with less resolution; one approximation image and three (horizontal, vertical, and diagonal) detail images. In this study, the IHS was combined with multiresolution wavelet decomposition according to the scheme shown in Figure (3) where the wavelet model decomposed both the PAN and I images and then the detail images of the PAN were injected into the I image. In his study two most common wavelet models were used namely; Mallat model (Gonzalez et al., 2004 and Amolins et al., 2007) and à trous model (Núñez, et al., 1999). Two injection procedures were also applied; substitution and addition. In substitution procedure, the detail images of I component are completely replaced by those of the PAN image. In addition procedure, the detail images of PAN image are added to those of I component. As a result four IHS with wavelet methods were applied. The abbreviations of these methods are (IHS+WMA), (IHS+WMS), (IHS+WTA), and (IHS+WTS) where M or T refers to the wavelet model (Mallat or à Trous) and S or A refers to the injection procedure (Substitution or Addition) respectively.

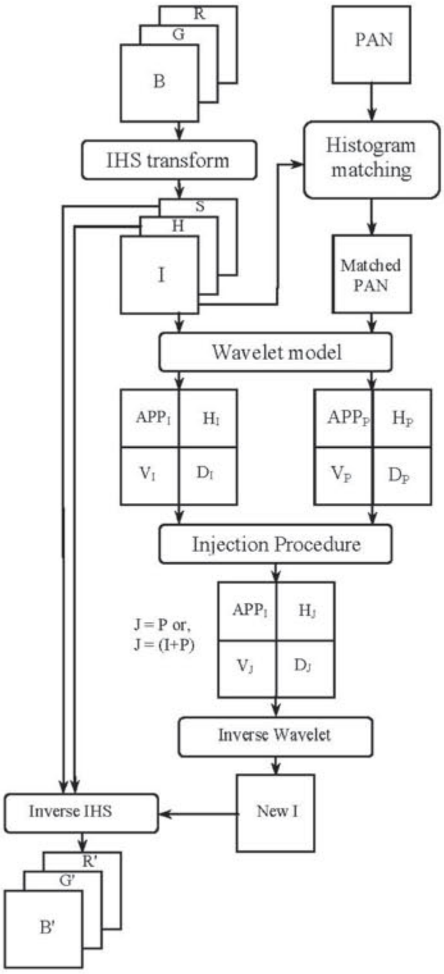



Figure 3: Scheme of IHS with Wavelet fusion methods

## 4. Experiments and Results

Nine IHS-based fusion methods were applied to merge the two data sets of QuickBird PAN and MS images. These methods are as follows:

- Traditional IHS (IHS)
- Three methods of IHS with spectral adjustment (IHS+$SA_{1,2,3}$)
- IHS with a tradeoff parameter (IHS+TP)
- Four methods IHS with wavelet transform (IHS+WMA), (IHS+WMS), (IHS+WTA), and (IHS+WTS)

After registering the MS image of each set to its corresponding PAN image, the MS images were up sampled using cubic interpolation so that the pixel size of MS bands equals that of the PAN image (0.6 m). Then different fusion techniques were applied. Figures (1 and 2) show the fused images for the two data sets. To statistically evaluate the spectral quality of the fused images, they were first degraded to their original spatial resolution (2.4 m) using bicubic resembling, and then compared to the original MS bands by computing the following quantitative parameters:

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

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

Equation 8

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.

- 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 9

Where,

h = the resolution of the high spatial resolution image.

l = the resolution of the low spatial resolution image.

N = number of bands.

$\bar{A_k}$ = 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 10

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

n = number of pixels.

Tables (1 and 2) show the correlation coefficients and the ERGAS index values for the two data sets. 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). The high correlation coefficients indicate that most of the spatial information of the PAN image was injected into the MS image during the fusion process. Tables (1 and 2) show the correlation coefficients between the filtered PAN and the filtered fused images obtained by different methods for the two data sets.

**5. Analysis of Results**

From Tables (1 and 2), it can be noted that the traditional IHS provided the least spectral quality (i.e. the least correlation coefficients between the fused images and the original MS images) 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 each of the MS bands. As shown in figure (4), the PAN wavelength range is extended from the visible to the NIR bands and even far beyond the NIR wavelength range. The PAN sensitivity is low in green range and extremely lower in blue range. This obviously leads to significant gray level differences between the original PAN and the I image that is derived from the original MS bands and consequently introduces high color distortions in the fused images. Visually the color distortion is clear, as shown in figures (1-c, and 2-c), especially in vegetation areas. The spectral quality obtained using any of the three IHS with spectral adjustment methods or the IHS with a tradeoff parameter method is higher than that obtained using the traditional IHS method. Visually, the colors of different features are closer to the original MS bands. These improvements can be referred to the consideration of the NIR band in the definition of the I image that minimizes the gray level differences between PAN and I images. The IHS with wavelet decomposition methods provided statistically the highest correlation coefficients between the fused and the original MS images. Visually, Mallat wavelet model provided fused images with slightly closer colors to the original MS images than those obtained using the à trous model. The spectral quality obtained using the addition injection procedure is higher than that obtained using the substitution injection procedure. This is because in addition procedure the detail images of I component were added to and not replaced by, as in the substitution procedure, those of the PAN image. Thus, all the detail information of I image was preserved and all the detail images of PAN and I were used.

Table 1: The correlation coefficients for Tanta data set

| CCs | IHS | IHS+SA$_1$ | IHS+SA$_2$ | IHS+SA$_3$ | IHS+TP | IHS+WTA | IHS+WTS | IHS+WMA | IHS+WMS |
|---|---|---|---|---|---|---|---|---|---|
| R/R' | 0.8057 | 0.9396 | 0.9381 | 0.9330 | 0.9618 | 0.9766 | 0.9756 | 0.9842 | 0.9810 |
| G/G' | 0.6884 | 0.8838 | 0.8834 | 0.8758 | 0.9257 | 0.9571 | 0.9565 | 0.9707 | 0.9653 |
| B/B' | 0.5345 | 0.8205 | 0.8226 | 0.8427 | 0.8835 | 0.9359 | 0.9353 | 0.9545 | 0.9486 |
| PAN/R' | 0.9383 | 0.9560 | 0.9613 | 0.9300 | 0.9413 | 0.8847 | 0.8734 | 0.7927 | 0.7912 |
| PAN/G' | 0.9394 | 0.9587 | 0.9614 | 0.9301 | 0.9479 | 0.8855 | 0.8775 | 0.7902 | 0.7897 |
| PAN//B' | 0.9281 | 0.9551 | 0.9592 | 0.9187 | 0.9442 | 0.8819 | 0.8761 | 0.7830 | 0.7815 |
| ERGAS | 3.1149 | 1.7659 | 1.8468 | 2.5587 | 1.4128 | 1.1378 | 1.2022 | 0.9159 | 1.0522 |

Table 2: The correlation coefficients for Alexandria data set

| CCs | IHS | IHS+SA$_1$ | IHS+SA$_2$ | IHS+SA$_3$ | IHS+TP | IHS+WTA | IHS+WTS | IHS+WMA | IHS+WMS |
|---|---|---|---|---|---|---|---|---|---|
| R/R' | 0.8867 | 0.9436 | 0.9424 | 0.9361 | 0.9638 | 0.9782 | 0.9765 | 0.9893 | 0.9869 |
| G/G' | 0.8854 | 0.9414 | 0.9392 | 0.9306 | 0.9613 | 0.9773 | 0.9756 | 0.9882 | 0.9857 |
| B/B' | 0.7535 | 0.8645 | 0.8634 | 0.8583 | 0.9107 | 0.9639 | 0.9573 | 0.9825 | 0.9684 |
| PAN/R' | 0.9712 | 0.9763 | 0.9772 | 0.9710 | 0.9733 | 0.9414 | 0.9243 | 0.8462 | 0.7941 |
| PAN/G' | 0.9694 | 0.9759 | 0.9765 | 0.9687 | 0.9742 | 0.9376 | 0.9277 | 0.8477 | 0.7899 |
| PAN//B' | 0.9672 | 0.9752 | 0.9757 | 0.9669 | 0.9726 | 0.9332 | 0.9296 | 0.8406 | 0.7823 |
| ERGAS | 4.6231 | 3.3632 | 3.4188 | 3.8623 | 2.6879 | 1.8286 | 1.8813 | 1.3954 | 1.5437 |

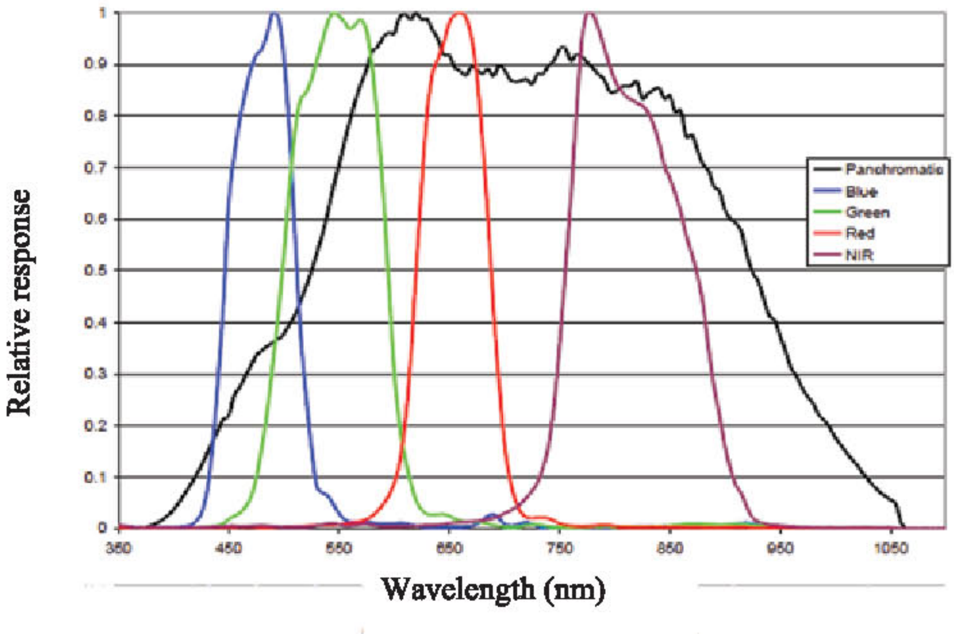



Figure 4: Spectral response of QuickBird imagery. (adopted from DigitalGlobe)

The computed values of ERGAS index for different fusion techniques indicated that the IHS with Mallat wavelet model and addition injection procedure (IHS + WMA) is spectrally the superior fusion technique since it provided the least ERGAS values for both data sets. All the applied fusion techniques have introduced spatial details but the degree of sharpness varies in the fused images. The edges in Tanta area and small objects like cars in Alexandria area are clearly visible. Among all the methods, the three IHS with spectral adjustment methods and the IHS with a tradeoff parameter method have produced the highest and also very close spatial quality. They are followed by the traditional IHS method and eventually, with the least spatial quality, the IHS with wavelet decomposition methods. Although Mallat fused images are spectrally slightly better than à trous fused images, the à trous model provided fused images with better appearance than those using Mallat model. This is because the à trous fused images are sharper and having considerably higher spatial quality than those obtained using the Mallat model. Generally, the obtained spatial quality due to applying a certain fusion method is higher in Alexandria site (urban area) than in Tanta site (agricultural area). This can be attributed to the nature of the land cover classes of the area under consideration.

## 6. Conclusion

This study showed the capability of IHS-based fusion techniques to successfully produce high spatial resolution multispectral images with various degrees of spatial and spectral qualities. The traditional IHS technique has provided fused images with considerably high spatial details but, as expected, with also significant color distortions. All the other applied methods have improved the spectral quality of the fused images. The improvements in the spectral quality due to using IHS with spectral adjustments and with a tradeoff parameter are referred to the consideration of the near infrared band in the definition of the intensity image. This leads to minimizing the radiance differences between the panchromatic and the intensity images. The IHS with wavelet transform methods has produced the highest spectral quality but the least spatial quality. Mallat wavelet model behaves spectrally better than à trous model but the à trous model provides considerably better spatial quality than the Mallat model. The addition injection procedure produces higher spectral and spatial qualities than those obtained using the substitution procedure. Regarding its fast and simple computing capability, the IHS with a tradeoff parameter is a very suitable technique to merge panchromatic and multispectral images since it provides not only a high spectral quality but also a reasonable spatial quality.

This study demonstrated that the improvement of the spectral quality due to applying a certain method means the deterioration of the spatial quality and vise versa. There is no single fusion technique that is valid for various applications. The selection of an appropriate fusion technique depends mainly on the application requirements that might be an enhanced natural-colored image for better visualization, a sharper and greater detail in color image for more accurate mapping or a classification oriented fused image.

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