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Implementation of Fusion Techniques on GeoEye-1 Satellite Imagery

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ملخص البحث

يتم تعريف دمج الصور بشكل عام على أنه تقنية تستخدم للجمع بين المعلومات المكانية العالية للصورة البانورامية (PAN)مع المعلومات الطيفية العالية للصورة متعددة الأطياف (MS) لإنتاج صورة متعددة الأطياف ذات الدقة المكانية العالية. في هذه البحث تم تطبيق ستة تقنيات دمج للصورة لدمج التفاصيل المكانية والطيفية لإنتاج صور مدمجة بأعلى الصفات المكانية والطيفية. تم تطبيق تقنيات الدمج على ثلاث مجموعات من صور(PAN) و (MS) للقمر الصناعى GeoEye-1 تغطي أغطية أرضية مختلفة في مدينة طنطا ، مصر.
تستخدم تقنيات الدمج المستخدمة تحويلات طيفية ومكانية مختلفة ، وهي:
Fast-Intensity-Hue-saturation (FIHS), FIHS with Area Model (FIHS+ Area), Principle Component Analysis (PCA), Gram Schmidt Fusion (GS), Hyper-spherical color space (HCS), and Ehlers fusion (Ehlers)
الغرض من هذه الدراسة هو تقييم ومقارنة الصفات الطيفية والمكانية للصور المدمجة نتيجة تطبيق تقنيات الدمج المختلفة. تتم مقارنة الصور المدمجة بصريًا وإحصائيًا مع صور (PAN) و (MS) الأصلية. أظهرت النتائج أن طريقة (FIHS + Area) قد حسنت بشكل كبير من جودة الطيف مع الحفاظ على المعلومات المكانية لصورة (PAN)الأصلية. يعتمد اختيار تقنية الدمج المناسبة بشكل أساسي على متطلبات التطبيق المستخدم.

Abstract

Image fusion is generally defined as a technique that is used to combine the high spatial information of the panchromatic image (PAN) with the high spectral information of the multispectral image (MS) to produce a high spatial resolution multispectral image. In this paper, six image fusion techniques were applied to merge the spatial and the spectral details to produce fused images with the highest spatial and spectral qualities. The fusion techniques were applied for three sets of GeoEye-1 PAN and MS images covering different land covers in Tanta city, Egypt.

The applied fusion techniques utilize different spectral and spatial transformations, they are: Fast-Intensity-Hue-saturation (FIHS), FIHS with Area Model (FIHS+ Area), Principle Component Analysis (PCA), Gram Schmidt Fusion (GS), Hyper-spherical color space (HCS), and Ehlers fusion (Ehlers). The purpose of this study is to evaluate and compare the spectral and spatial qualities of the fused images due to applying different fusion techniques. The fused images are compared visually and statistically to the original PAN and MS images. The results revealed that the (FIHS+ Area) method has considerably improved the spectral quality while preserving the spatial information of the original PAN image. The selection of an appropriate fusion technique depends mainly on the requirements of the application in hand.

Keywords:

Image Fusion, Fast-Intensity-Hue-Saturation (FIHS), Principle Component Analysis (PCA), Gram Schmidt (GS), Hyper-spherical color space (HCS), Ehlers fusion.

1. Introduction

Earth observation satellites provide data at a broad range of characteristics and multisource imageries including; spectral, spatial, radiometric, and temporal resolutions. By combining these data that use different physical principals and record different properties of the objects, this may generate datasets that have more information than each of the input data alone. This process of combining several kinds of imagery is known as data fusion. Several definitions can be found: "Data fusion is capable of integrating different imagery data to produce more information than can be derived from a single sensor" (Pohl and Van Genderen, 1998). Another comprehensive definition: "Data fusion deals with the synergistic combination of information made available by various knowledge sources such as sensors, in order to provide a better understanding of a given scene". The benefits from the fused images vary, they may detect the changes occurred over a period of time, enhance spatial resolution of multispectral images, generate an interpretation of the scene not obtainable with data from a single sensor, and reduce the uncertainty associated with the data from individual sensor. They generally offer increased interpretation capabilities, achieve more specific inferences and produce more reliable results (Elsherif at al., 2014).

Modern earth observation satellites such as GeoEye, Worldview, Ikonos, and Quickbird acquire image data in two different modes, a low spatial resolution multispectral (MS) mode and a high spatial resolution panchromatic (PAN) mode. The PAN images are high resolution images but they are black and white images. The MS images are color images but low spatial resolution images. The PAN images are taken by a single band and the MS images are taken by using various bands. Actually, earth observation satellites cannot collect high spatial resolution MS images directly because of some technical limitations. On the other hand, many remote sensing applications require images that simultaneously have high spatial and high spectral resolutions. So, the most effective solution for obtaining high resolution MS images is the fusion of the PAN images and MS images. GeoEye-1 satellite provides PAN images at 0.41 m ground resolution and MS images in four bands (blue, green, red, and near infrared) at 1.64 m ground resolution.

In this search, six commonly used fusion techniques are explained and applied to merge three datasets of GeoEye-1 PAN and MS images covering different land covers of Tanta city in Egypt. The applied fusion techniques are: Fast Intensity - Hue - Saturation (FIHS) fusion technique, (FIHS + Area) fusion technique, Principal Component Analysis (PCA) fusion technique, Gram- Schmidt (GS) fusion technique, Hyperspherical Color Space (HCS) fusion technique, Ehlers Fusion technique.

The IHS, PCA, GS, and HCS fusion techniques are based on the spectral transformations between RGB color space and IHS, PCA, GS, and HCS color spaces respectively. The IHS+Area fusion technique is a modified IHS with different weighting parameters for each band of the MS image. Ehlers fusion technique is based on Fourier transform of the digital image at the frequency domain. Regarding the different theoretical principle for each of these six image fusion techniques it is worth to study the effect of each on the spatial and spectral qualities of the resulted fused images.

Therefore, the aim of this paper is to compare the performance and to assess the effect of each fusion technique on the spatial and spectral properties of the fused images. The processing steps of this study were performed by the aid of PCI, ENVI and ERDAS digital image processing software packages.

2. Study Site and Data Sets

The entire PAN and MS images were acquired by GeoEye-1 on May 11, 2011 covering Tanta city, Elgharbiya governorate, Egypt. The PAN and MS images are shown in figure (1). The MS image was first registered to the PAN image using AUTOGCP module in PCI software where the ground control points were automatically collected based on the normalized cross-correlation approach. The cubic convolution resampling technique was then applied to determine the digital values of each pixel in the registered MS image. The accuracy of the registration process is less than quarter a pixel. After registration and resampling the MS image, three subsets were cut out from the PAN and the registered MS images. Each data set comprises a PAN subscene and its corresponding registered MS subscene. The three data sets were chosen to cover different land cover classes namely; urban, agricultural, and mixed areas. In each data set, the PAN and MS images are of size 1024 pixels by 1024 pixels, 0.5 m each. Figures (2), (3), and (4) show the three data sets.

3. Image Fusion Techniques

3.1. IHS fusion method

The IHS fusion method uses three low resolution MS bands and transforms them from RGB color space to IHS color space which offers the advantage that the separate components outline certain color properties as follows (Firouz et al., 2011):

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

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

Variables v_1 and v_2 can be considered as *x, y* axes in the Cartesian coordinate system while intensity I indicates the *z* axis.

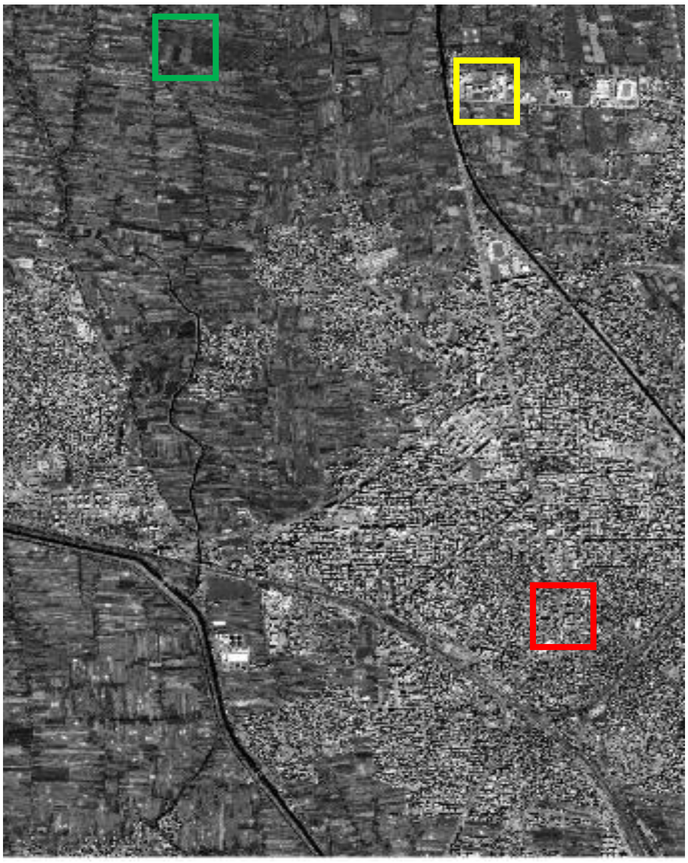

Figure (1a): The entire PAN image and the study data sets

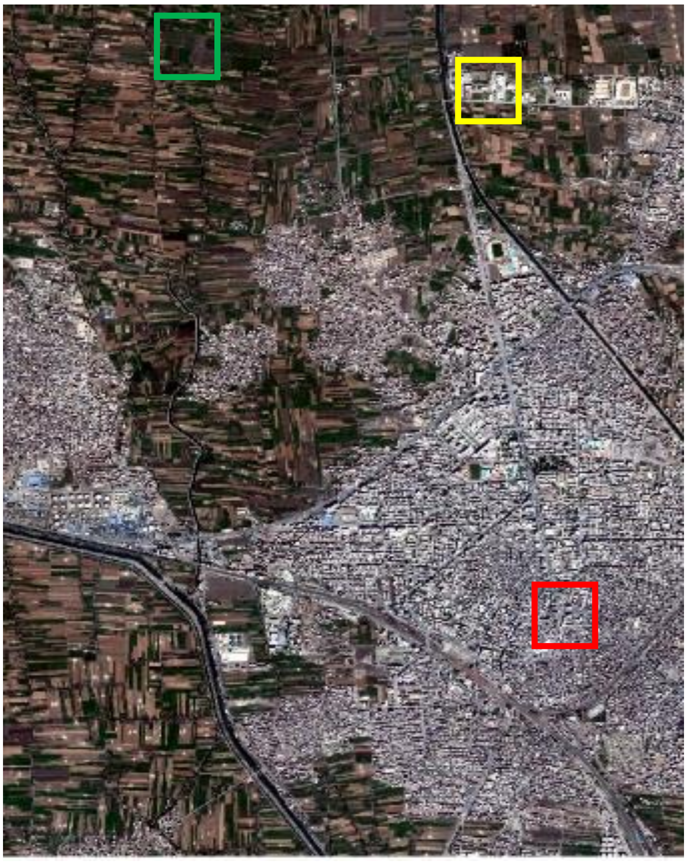

Figure (1b): The entire MS image and the study data sets

Urban

Agricultural

Figure (2): GeoEye-1 data set 1 (Urban area)

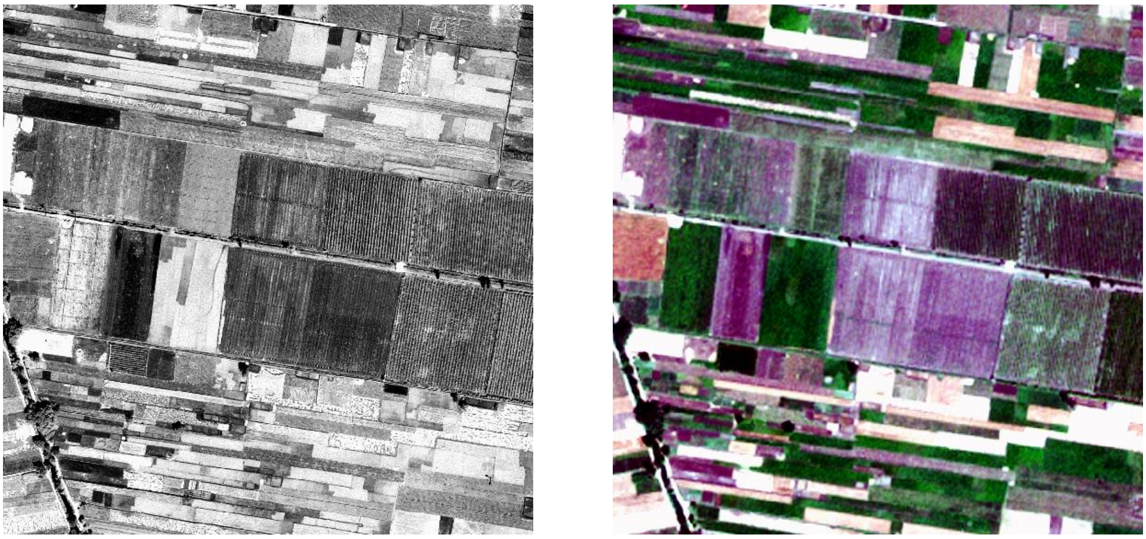

Figure (3): GeoEye-1 data set 2 (Agricultural area)

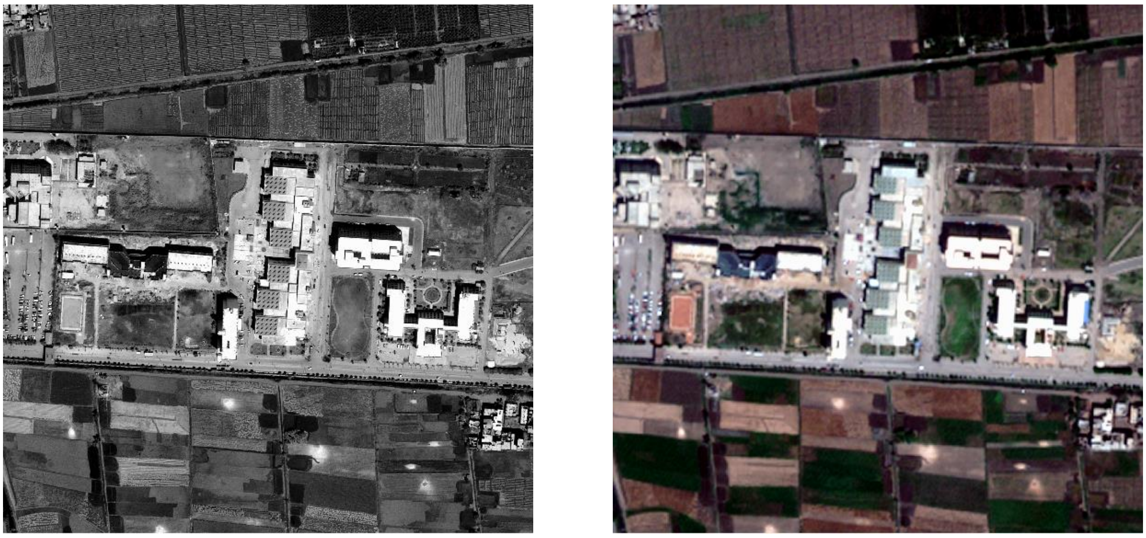

Figure (4): GeoEye-1 data set 3 (Mixed area)

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

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

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R + \delta \\ G + \delta \\ B + \delta \end{bmatrix} \tag{2}$$

Where,

R', G', B' are the fused images, and $\delta = (Pan - I)$

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, as the difference (δ) increases, more color distortion is expected to appear in the fused image as a result of mismatches, that is the Pan and I images are spectrally dissimilar (Zhang, 2004).

3.2. (IHS + Area) fusion method

The IHS+Area fusion technique is based on the fast IHS (FIHS) fusion technique previously described in equation (2). The aim is to derive a new modified intensity image I that minimizes the radiance difference (δ) between Pan and I images. The achievement of the IHS fusion technique using equation (2) allows the extension of traditional three-order transformation to an arbitrary order. This means that the NIR band can be included in the definition of I component (Tu et al., 2004) and the (FIHS) fusion can be represented as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + \delta_1 \\ G + \delta_1 \\ B + \delta_1 \\ NIR + \delta_1 \end{bmatrix} \tag{3}$$

Where,

$$I_1 = (R + G + B + NIR)/4 \tag{4}$$

$\delta_1 = (PAN - I_1)$

Equation (4) stated that in FIHS all the MS bands are equally considered to derive the new intensity component. However, taking into consideration that the measured energy in an individual channel is sum (integral) of incoming radiation and relative spectral sensitivity, it is theoretically possible to obtain the values in the PAN band with the summation of respective spectral bands. Unfortunately the spectral response curve of the PAN band does not completely cover the MS bands.

Afify, (2012) suggested using different weighting parameters determined according to the intersection area between the spectral response curve of each MS band and that of the PAN band to assign the contribution of each MS band in the derived I component. 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. A new intensity component can be determined after introducing the calculated weighting parameters for all the bands of GeoEye-1 as follows:

$$I_{new} = 0.307\ (B) + 0.386\ (G) + 0.198\ (R) + 0.109\ (NIR \qquad (5)$$

In addition an appropriate tradeoff parameter in the interval [0, 1] was then used to improve the spectral characteristics of the fused images. Hence, the IHS+Area fusion technique can be expressed as follows (Afify, 2012):

$$\begin{bmatrix} R' \\ G' \\ B' \\ NIR' \end{bmatrix} = \begin{bmatrix} R + t.(PAN - I_{new}) \\ G + t.(PAN - I_{new}) \\ B + t.(PAN - I_{new}) \\ NIR + t.(PAN - I_{new}) \end{bmatrix} \qquad (6)$$

In this study the appropriate tradeoff parameter (t) is taken equal to 0.7 for urban and mixed datasets and 0.6 for agricultural dataset.

3.3. PCA fusion method

The PCA fusion method is based on the spectral transformation from RGB color space to PCA color space to transform the original correlated MS bands into a set of uncorrelated principal components (PCs). The uncorrelated PCs will be ranked in terms of the variance they explain from the original bands (Ricotta et al., 1999). The first principal component has the highest variance compared to the rest and it is followed by the second one and so on for the following components. So, the first two or three components usually contain most of the information (over than 95%) involved in the original MS bands. The PCA fusion technique assumes that the first component PC1 contains the overall scene luminance (Pohl and Van Genderen, 1998) and is similar to the data presented in the PAN image (Chavez et al., 1991). Based on the previous assumption, the PAN image substitutes the PC1 after being scaled to match the histogram of the PC1 component. The histogram matching aims to preserve the shape of the PAN image histogram, as well as making it lie in the same numerical range of the PC1. This process is done so that the mathematics of the reverse transform doesn’t distort the thematic information (Ehlers et al., 2010). Finally, an inverse PCA transform is applied to the matched PAN image and the rest of PC components to obtain the fused images.

3.4. GS fusion method

The Gram-Schmidt pan-sharpen fusion technique has become one of the most popular algorithms to pan-sharpen multispectral (MS) imagery. It simulates a panchromatic band from the lower spatial resolution spectral bands. In general, this is achieved by averaging the multispectral bands. As the next step, a Gram-Schmidt transformation is performed on the simulated panchromatic band and the multispectral bands, where the simulated panchromatic band is employed as the first band. The histogram of the PAN image was matched to the histogram of the GS1 component. Then the histogram-matched PAN image replaces the first Gram-Schmidt band. Finally, an inverse Gram-Schmidt transform is applied to create the pan-sharpened multispectral bands (Maurer, 2013).

3.5. HCS fusion method

In HCS fusion technique the image data is transformed from RGB color space to hyper-spherical color space (Padwick et al., 2010). Two modes of HCS pan-sharpening algorithm can be applied. The first mode is called the naïve mode and simply replaces the multispectral intensity component with an intensity matched version of the PAN band. The steps for the naïve mode are: Firstly the intensity component (I) is computed from the MS bands. Secondly the forward transform from the RGB color space to the hyper-spherical color space is performed. Thirdly the square of the PAN image (P^2) is matched to the square of the intensity component (I^2). Fourthly the sharpening step is performed by forming the adjusted intensity by taking the square root of matched P^2 and the resulting I_{adj} is the pan-sharpened intensity and fifthly the sharpening algorithm proceeds by directly substituting the quantity I_{adj} for I in the reverse transformation from HCS color space back to the original color space.

The second mode is called the smart mode. The steps for the smart mode are: Firstly prior to sharpening the image a smoothed version of the panchromatic band (PS) is formed, where the SMOOTH operation is simply a sliding window convolution filter, performed with a 7x7 square window, in which the value of the middle output pixel is the mean of all pixels in the window. The goal is to match the multi-spectral resolution as best as possible. Secondly the intensity component (I) is computed from the MS bands. Thirdly the forward transform from the RGB color space to the hyper-spherical color space is performed. Fourthly the square of the PAN image (P^2) and the square of the smoothed PAN image (PS^2) are matched to the square of the intensity component (I^2). Fifthly the sharpening step is performed by forming the adjusted intensity by taking the square root of $(P^2/PS^2)*I^2$ and the resulting I_{adj} is the pan-sharpened intensity and sixthly the sharpening algorithm proceeds by directly substituting the quantity I_{adj} for I in the reverse transformation from HCS color space back to the original color space.

3.6. Ehlers fusion method

The principal idea behind image fusion that preserves spectral characteristics of MS image is that the PAN image has to sharpen the MS image without adding new gray-level information to its spectral components. To facilitate these demands, two prerequisites have to be addressed. First, color and spatial information have to be separated. Second, the spatial information content has to be manipulated in a way that allows adaptive enhancement of the images. This is achieved by a combination of color and Fourier transforms (Ehlers and Klonus, 2007).

The first step is the transformation of the multispectral image into an IHS image that works with three bands at each step. Then normalize the grey-value range of the PAN to the I component of the IHS image. A subsequent Fourier transform of the intensity component and the PAN image allows an adaptive filter design in the frequency domain. Using Fourier transform techniques, the spatial components to be enhanced or suppressed can be directly accessed. The panchromatic image and the intensity component were transformed into the frequency domain using a two-dimensional Fast Fourier Transform (FFT). For the design of the appropriate low-pass filter for the intensity component and the respective high pass filter for the panchromatic image, the power spectra of both images were used. Ideally, the low-pass filter for the intensity component of the resampled multispectral image should be inverse to the high-pass filter for the enhancement of edges in the panchromatic image.

After filtering, the images were transformed back into the spatial domain with an inverse FFT. The two images were added together to form a fused intensity component with the low-frequency information from the low-resolution multispectral image and the high-frequency information from the high-resolution panchromatic image. The fused image was histogram matched to the original intensity component to map the fused image into the spectral range of the original image. This new intensity component and the original hue and saturation components of the multispectral image formed a new IHS image. An inverse IHS transformation was then performed to produce a fused RGB image that contains the spatial resolution of the panchromatic image and the spectral characteristics of the multispectral image.

4. Experiments and Results

After registering the MS image of each set to its corresponding PAN image, the MS images were upsampled using cubic convolution so that the pixel size of MS bands equals that of the PAN image (0.5 m). Then the fusion techniques were applied to merge the three data sets of GeoEye-1 images. Figures (5, 6, and 7) show the fused images for the three data sets.

To statistically evaluate the spectral quality of the fused images, they were compared to the original MS bands by computing the following quantitative parameters:

1- The correlation coefficients (CCs) between the fused bands and the original MS bands where,

$$\mathrm{CC}\ (A/B) = \frac{\sum_{i=1}^{n}(A_i - \overline{A})\,(B_i - \overline{B})}{\sqrt{\sum_{i=1}^{n}(A_i - \overline{A})\sum_{i=1}^{n}(B_i - \overline{B})}} \qquad (7)$$

where

A_i and B_i = the pixel values of the original and fused images.
$\overline{A}$ and $\overline{B}$ = the mean 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 the 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:

$$\mathrm{ERGAS} = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{k=1}^{N}\frac{\mathrm{RMSE}^2\,(A_k)}{\overline{A}_k{}^2}} \qquad (8)$$

Where,
h = the resolution of the high spatial resolution image.
l = the resolution of the low spatial resolution image.
N = number of bands.

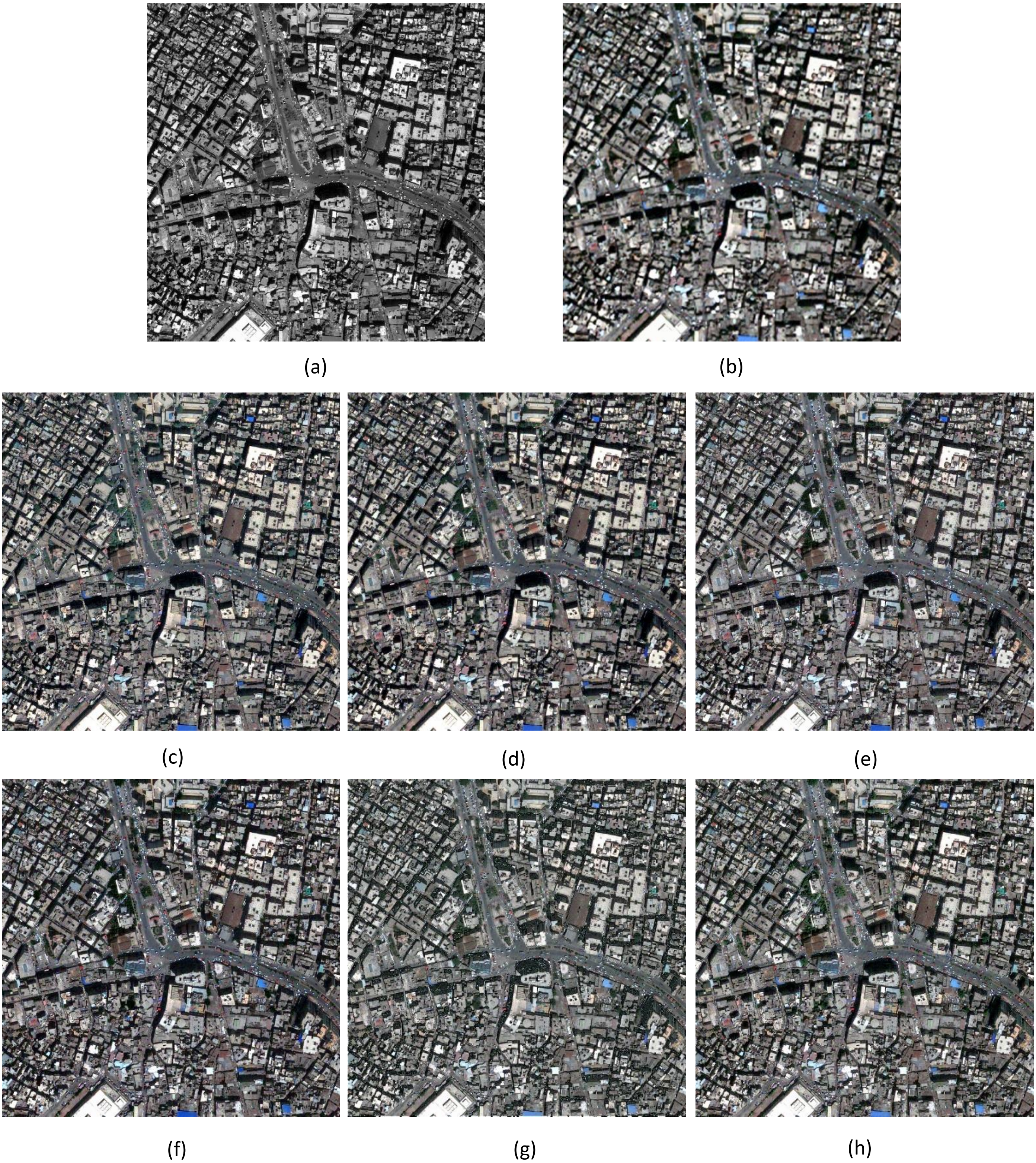

Figure 5: The original and fused images of GeoEye-1 urban area, (a) Original PAN, (b) Original MS, (c) FIHS, (d) FIHS +Area, (e) PCA, (f) GS, (g) HCS, (h) Ehlers

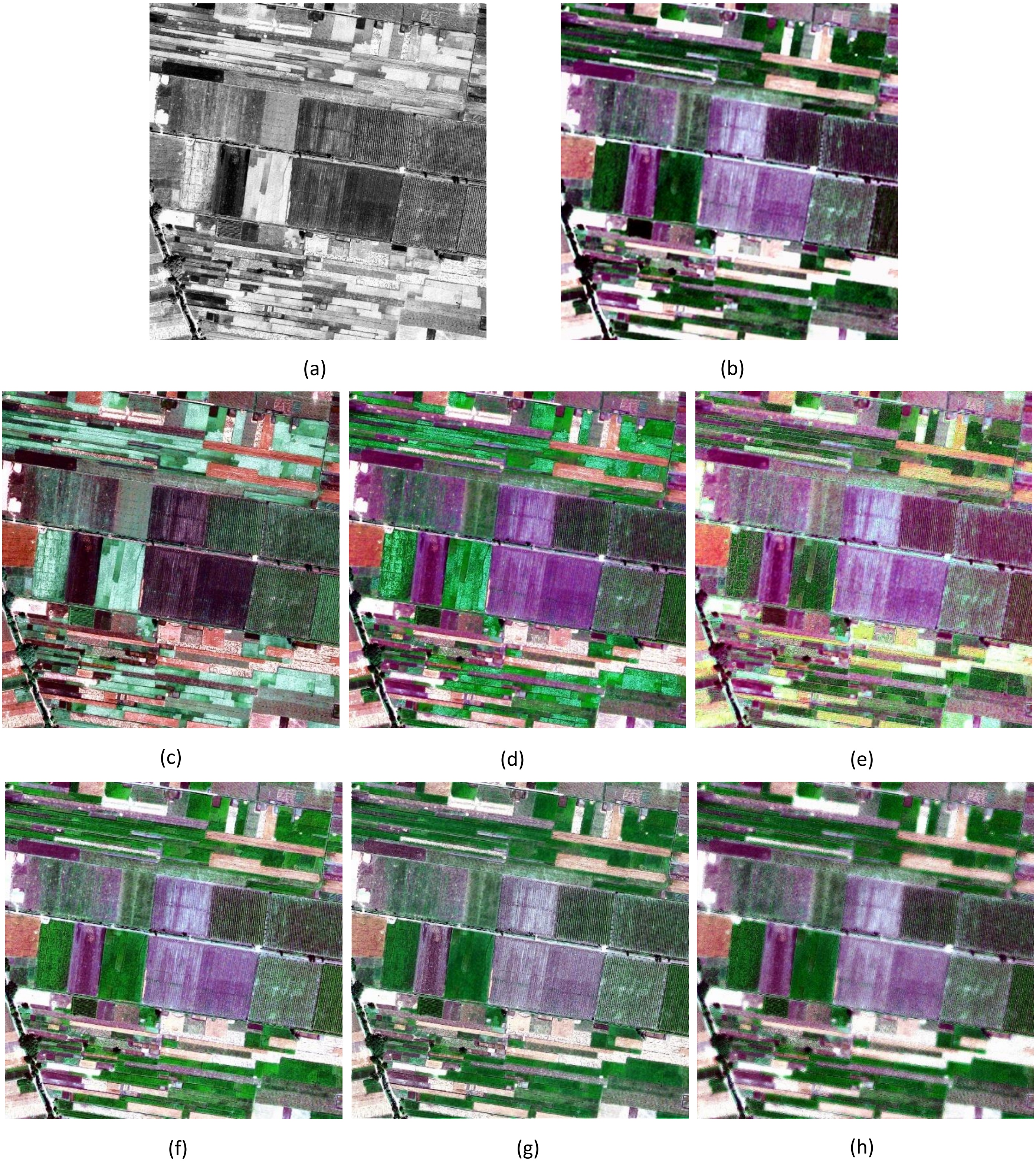

Figure 6: The original and fused images of GeoEye-1 agricultural area, (a) Original PAN, (b) Original MS, (c) FIHS, (d) FIHS +Area, (e) PCA, (f) GS, (g) HCS, (h) Ehlers

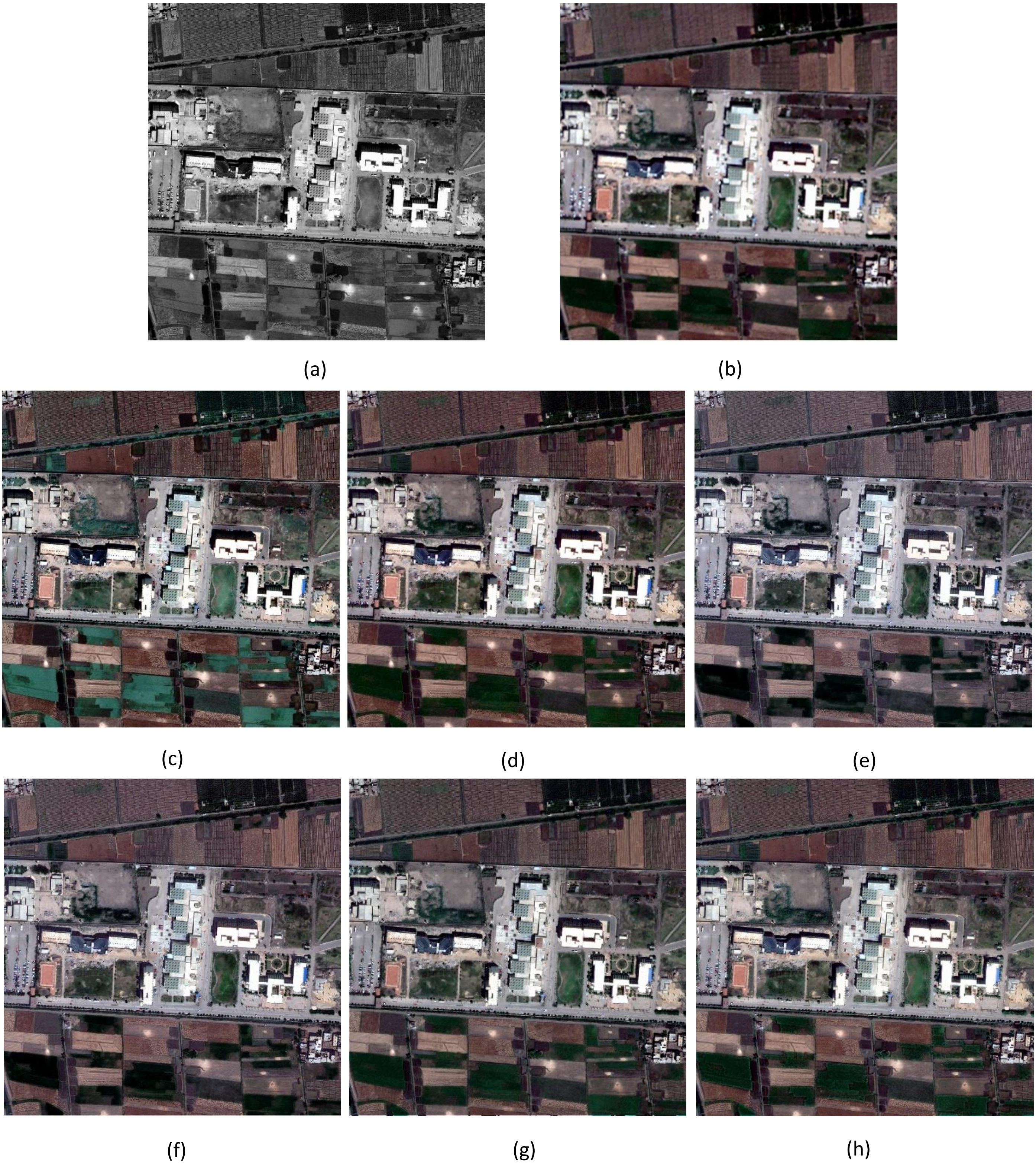

Figure 7: The original and fused images of GeoEye-1 mixed area, (a) Original PAN, (b) Original MS, (c) FIHS, (d) FIHS +Area, (e) PCA, (f) GS, (g) HCS, (h) Ehlers

$\overline{A}_k$ = the mean values of the original band k.

RMSE (A) = the root mean square error that can be computed as follows:

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

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

n = number of pixels.

Tables (1, 2, and 3) show the correlation coefficients and the ERGAS index values for the three 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. Then the average of the correlation coefficients is calculated and used to determine the overall spatial quality of the fused image. 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. The correlation coefficients between the filtered PAN and the filtered fused images by different methods for the three data sets are shown in tables (1, 2, and 3).

5. Analysis of Results

From the results in tables (1), (2) and (3), it can be noted regarding the spectral quality that:

The fusion techniques FIHS+AREA, and Ehlers have provided the highest spectral quality for the three data sets. Moreover, The FIHS+AREA fusion technique has provided spectral quality that is much better than the Ehlers fusion technique for dataset 1, and 3 (urban and mixed areas). While for dataset 2 (agricultural area), The Ehlers fusion technique has provided spectral quality that is better than the FIHS+ AREA fusion technique.

Criterion	FIHS	FIHS +Area	PCA	GS	HCS	Ehlers
CC Red	0.9122	0.9557	0.8832	0.8784	0.8464	0.8924
CC Green	0.8699	0.9333	0.8830	0.8776	0.8168	0.8680
CC Blue	0.8246	0.9085	0.8865	0.8807	0.8214	0.8748
CC NIR	0.9409	0.9702	0.8835	0.8808	0.8542	0.9123
CC (Av.)	0.8869	0.9419	0.8841	0.8794	0.8347	0.8869
ERGAS	5.4119	3.8373	5.5513	5.6604	9.0882	5.4933
HPF CC Red	0.9623	0.9506	0.9507	0.9949	0.8519	0.9693
HPF CC Green	0.9625	0.9554	0.9469	0.9908	0.8190	0.9564
HPF CC Blue	0.9619	0.9555	0.9416	0.9836	0.8126	0.9540
HPF CC NIR	0.9562	0.9407	0.9512	0.9926	0.8638	0.9726
HPF CC (Av.)	0.9607	0.9506	0.9476	0.9905	0.8368	0.9631

Table 1: Evaluation criteria (the correlation coefficients and ERGAS) for data set 1 (Urban area)

Criterion	FIHS	FIHS +Area	PCA	GS	HCS	Ehlers
CC Red	0.6414	0.9693	0.7577	0.9490	0.9353	0.9703
CC Green	0.3863	0.8778	0.9598	0.8834	0.8245	0.8855
CC Blue	0.2180	0.9048	0.7553	0.9355	0.8912	0.9416
CC NIR	0.9871	0.9944	0.6070	0.9752	0.9316	0.9832
CC (Av.)	0.5582	0.9366	0.7700	0.9358	0.8957	0.9452
ERGAS	10.6594	3.6467	8.4212	3.7090	5.3351	3.3275
HPF CC Red	0.8850	0.8059	0.9275	0.9860	0.8722	0.9208
HPF CC Green	0.8853	0.8139	0.9112	0.9873	0.9314	0.9496
HPF CC Blue	0.8851	0.8115	0.9266	0.9762	0.8907	0.9372
HPF CC NIR	0.8681	0.7733	0.9113	0.9805	0.8930	0.9393
HPF CC (Av.)	0.8809	0.8012	0.9192	0.9825	0.8968	0.9367

Table 2: Evaluation criteria (the correlation coefficients and ERGAS) for data set 2 (Agricultural area)

Criterion	FIHS	FIHS +Area	PCA	GS	HCS	Ehlers
CC Red	0.9282	0.9750	0.9240	0.9354	0.9338	0.9595
CC Green	0.8969	0.9629	0.9110	0.9270	0.9210	0.9502
CC Blue	0.8786	0.9567	0.9182	0.9323	0.9001	0.9362
CC NIR	0.9687	0.9853	0.9323	0.9543	0.9018	0.9593
CC (Av.)	0.9181	0.9700	0.9214	0.9373	0.9142	0.9513
ERGAS	5.6214	3.3171	5.4776	4.8879	5.9837	4.6023
HPF CC Red	0.9831	0.9736	0.9415	0.9904	0.8846	0.9732
HPF CC Green	0.9834	0.9776	0.9427	0.9925	0.8679	0.9686
HPF CC Blue	0.9832	0.9770	0.9404	0.9895	0.8663	0.9679
HPF CC NIR	0.9705	0.9531	0.9402	0.9858	0.8795	0.9678
HPF CC (Av.)	0.9801	0.9703	0.9412	0.9896	0.8746	0.9694

Table 3: Evaluation criteria (the correlation coefficients and ERGAS) for data set 3 (Mixed area)

For the FIHS+ Area fusion technique, the reasons of the high spectral quality produced 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 use of the tradeoff parameters, and the use of the area weighting parameters to assign the contribution of each band in the derived I component.

For the Ehlers fusion technique, the reasons of the high spectral quality produced can be referred to the Fast Fourier Transform (FFT), which is used to transform the panchromatic image and the intensity component into the frequency domain, allows an adaptive filter design in the frequency domain. Using Fourier transform techniques, the spatial components to be enhanced or suppressed can be directly accessed. An appropriate low-pass filter is used for the intensity component and the respective high pass filter is used for the panchromatic image. The spatial details were added to the MS image without adding new gray-level information to its spectral components.

The ranking of the other fusion techniques from better to worse is FIHS, PCA, GS, HCS, for dataset 1 (urban area), and for dataset 2 (agricultural area) is GS, HCS, PCA, FIHS, while is GS, PCA, FIHS, HCS, for dataset 3 (mixed area). It seems that assessment the accuracy of a certain fusion technique is dependent on the nature of the scene area and the distribution of the different features involved in the scene.

The FIHS fusion technique produces low spectral quality because all bands are equally represented in the definition of the I component while there are differences in the spectral response curves between the PAN band and each of the MS bands. The spectral response curve for the GeoEye-1 satellite shows that the overlap of the green and blue bands with PAN is accepted, and the red band offers perfect overlap, while the overlap of the NIR band is poor. Obviously, the color distortion problem in FIHS fusion results from such mismatches, in that P and I are not spectrally similar. From the spectral response curve, it is expected that the highest color distortion in the fused bands will be in the NIR band.

The PCA and GS fusion techniques have provided closely spectral quality for dataset 1, and 3 (urban and mixed areas). While for dataset 2 (agricultural area), the GS fusion technique has provided spectral quality that is better than the PCA fusion technique.

The Ehlers and FIHS+ Area produced fused images almost spectrally undistorted in the three data sets. There is no significant spectral difference between the fused images of the two models visually. The FIHS, PCA, and GS fusion techniques produced some color distortion in the green areas. The HCS fusion technique produced some color distortion in the dark and shadow areas.

Regarding the spatial quality it can be noted from the same tables that:

All the applied fusion techniques have introduced spatial details but the degree of sharpness varies in the fused images. The edges and the field's boundaries in agricultural area and the small objects like cars in urban area are clearly visible in the fused images. Among all the methods, the GS fusion technique has provided the highest spatial quality for the three datasets.

The ranking of the other fusion techniques from better to worse is Ehlers, FIHS, FIHS+ Area, PCA, HCS, for dataset 1 (urban area), and for dataset 2 (agricultural area) is Ehlers, PCA, HCS, FIHS, FIHS+ Area, while is FIHS, FIHS+ Area, Ehlers, PCA, HCS, for dataset 3 (mixed area).

The visual inspection goes parallel to the statistical evaluation and shows that the GS fusion model produced high spatial quality in the three data sets. However, the statistical analysis indicated that the FIHS+ Area fused images are smoother than Ehlers fused images, but the visual inspection shows that the FIHS+ Area fused images are as sharp as the Ehlers fused images.

6. Conclusion

This study showed the capability of different fusion techniques to successfully produce high spatial resolution multispectral images with various degrees of spatial and spectral qualities. The FIHS+ Area and Ehlers fusion models superbly preserve the spectral quality of the fused images in different data sets and land covers.

Using the GS fusion technique improved the spatial quality better than that produced by FIHS+ Area and Ehlers fusion techniques, but the FIHS+ Area and Ehlers fusion techniques produced acceptable and stable spatial quality for different land covers.

This study demonstrated that the selection of the appropriate fusion technique depends on the target of the fused image. When the target is a fused image with the actual color combination of the original image, the FIHS+ Area and Ehlers fusion techniques are recommended. When the target is a fused image with the sharpness and the features edges of the original image, the GS fusion technique is recommended.

Regarding its fast and simple computing capability, the FIHS+ Area is capable of preserving high spectral and spatial quality whatever the type of land cover is. Therefore, the FIHS+ Area technique is chosen as the best fusion model among the tested fusion techniques.

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