An Improved Intensity-Hue-Saturation for A High-Resolution Image Fusion Technique Minimizing Color Distortion

Miloud Chikr El Mezouar, Nasreddine Taleb, Kidiyo Kpalma, and Joseph Ronsin

***Abstract*—Among the existing pan-sharpening methods, the Intensity-Hue-Saturation (IHS) technique is the most widely used one for its efficiency and high spatial resolution. When the IHS method is used for IKONOS or QuickBird imagery, there is a significant color distortion, due mainly to the range of wavelengths in the panchromatic (Pan) image. Based on the fact that the grey values of Pan in the green vegetated regions are far larger than the grey values of intensity (I), we propose to adjust spatially the I image, in the vegetated area only, in order to get grey values in the same range as those of the Pan image. We use the Normalized Difference Vegetation Index (NDVI) to identify the vegetation area and enhance the green (G) band by using the red (R) and the NIR bands. We obtain an intensity image with grey values comparable to the Pan's grey values. Hence the color distortion in the fused image is reduced. Visual and statistical analyses prove that the concept of the proposed method is promising, and it significantly improves the fusion quality compared to conventional IHS techniques.**

***Index Terms*—Image fusion, Intensity Hue Saturation (IHS) transformation, IKONOS, QuickBird, Normalized Difference Vegetation Index, Pan-sharpening.**

I. Introduction

EARTH observation satellites provide multispectral and panchromatic data having different spatial, spectral, temporal, and radiometric resolutions. The need for a single image, having all the complementary information from both multispectral and panchromatic images, has increased. A multispectral image with high spatial resolution may provide feature enhancement, increased classification accuracy, and helps in change detection. The designing of a sensor to provide both high spatial and spectral resolutions is limited by the tradeoff between spectral resolution, spatial resolution, and signal-to-noise ratio of the sensor. Hence, there is an increased use of image processing techniques to combine the available high spectral resolution multispectral image and high spatial resolution panchromatic image to produce a synthetic image that has both high spatial and spectral resolutions. These image processing techniques are known as pan-sharpening or resolution merge techniques. These methods try to preserve the spectral information of the multispectral image while trying to increase its spatial resolution [7]. Such techniques can largely extend the application potential of the raw remote sensing images.

The rest of the paper is organized as follows: in section 2, we will position the problem, in section 3 we will introduce our proposed approach followed by a quality assessment in section 4. Before concluding, we present some experimental results in section 5.

II. Problem Positionning

To date, various image fusion methods have been proposed in the literature [1], [2], [3], [4], [5], [6], and [11]. In [6], Tu et *al.* presented a fast computing method for fusing images. It can extend traditional three-order transformations to an arbitrary order. However, fast IHS fusion distorts color in the same way as other fusion processes such as the IHS fusion technique. To reduce this spectral distortion, Tu et *al.* presented a simple spectral-adjusted scheme integrated into a fast IHS method. In [3] Choi used a tradeoff parameter in a new approach for image fusion based on fast IHS fusion. This approach enables fast and easy implementation.

A. IHS transformation method

The IHS transform effectively transforms an image from the Red-Green-Blue (RGB) domain into spatial (I) and spectral (H, S) information. There are various models of IHS transformations available. Smith's triangular model is suitable for IHS sharpening [7].

The multispectral image is transformed from the RGB color space into the IHS domain. The intensity component is replaced by the panchromatic image and then transformed back into the original RGB space with the previous hue and saturation components.

B. High resolution satellite image fusion

When IHS-like fusion methods are used with IKONOS or QuickBird imagery, there is a significant color distortion, due primarily to the range of wavelengths in an IKONOS or

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QuickBird Pan image. Unlike the Pan images of SPOT and IRS sensors, IKONOS and QuickBird Pan images as shown in Fig. 1 have an extensive range of wavelengths from visible to near-infrared (NIR).

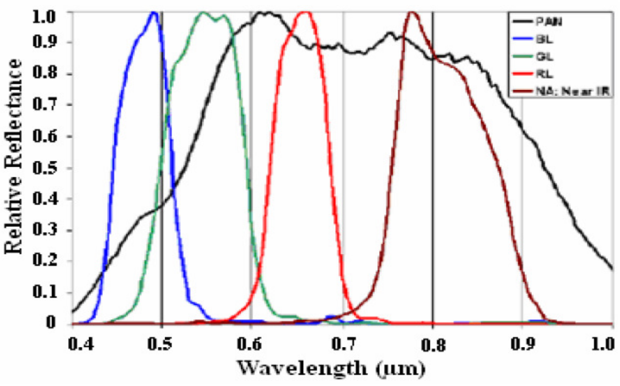

Fig. 1 Sensor bands of QuickBird2 remote sensing satellite.

This difference obviously induces the color distortion problem in the traditional IHS fusion as a result of the mismatches; that is, the Pan and I are spectrally dissimilar. In particular, the grey values of Pan in the green vegetated regions are far larger than the grey values of I because the areas covered by vegetation are characterized by a relatively high reflectance of NIR and Pan bands as well as a low reflectance in the RGB bands [3].

III. Proposed Approach

As mentioned in the latter section, the IHS fusion introduces color distortion when dealing with IKONOS or QuickBird images. To solve this problem, we propose a new technique: this approach makes use of the Normalised Difference Vegetation Index (NDVI) to identify the vegetation area and then enhances it in the green (G) band by using the red (R) and the NIR bands.

In this work, for high resolution satellite data fusion, we present a new approach to minimize the color distortion arising from the spectral mismatch between the Pan and MS bands. This color distortion is due to the fact that the grey values of Pan in the green vegetated regions are far larger than the grey values of I. To remedy to this problem we introduce some enhancement in the vegetation area to have grey values of Pan and MS in the same range and use the IHS transform to merge the boosted MS and Pan bands.

A. Detection of Vegetation

In the process of photosynthesis, live vegetation absorbs part of the solar radiation in the frequency region called photo-synthetically active radiation (PAR) spectral region. The absorbed solar energy includes the visible light from wavelengths of 0.4 to 0.68µm. Leaf cells reflect and transmit solar radiation in the near-infrared spectral region. Therefore, live vegetation has relatively low reflectance in the PAR and relatively high reflectance in the near-infrared region. Researchers studying terrestrial vegetation most often use sensors that are able to collect data in the near-infrared region of the spectrum. Near-infrared sensors are capable of measuring the chlorophyll contained in plant material.

The agricultural community is a frequent user of infrared remote sensing imagery [8]. However, the exact difference or ratio of the reflectance in the two regions, i.e. the PAR and the non-PAR spectral regions, varies from one vegetation type to the other. This makes possible devising vegetation indices that have some relationship to the amount and type of vegetation in a given image pixel. Vegetation indices (VI) are combinations of spectral measurements in different wavelengths as recorded by a radiometric sensor. They aid in the analysis of multispectral image information by shrinking multidimensional data into a single value. They serve as indicators of relative growth and/or vigor of green vegetation, and are diagnostics of various biophysical vegetation parameters.

The Normalized Difference Vegetation Index (NDVI) is an index calculated from reflectances measured in the visible and the near infrared channels.

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

Where NIR and R stand for the spectral reflectance measurements acquired in the near-infrared and red bands, respectively. NDVI varies between -1 and 1. It is related to the fraction of photo-synthetically active radiation. Vegetated areas typically have values greater than zero. The higher the NDVI, the more dense and more greener the vegetation.

B. New Fusion Technique

In this new approach, we propose to enhance the vegetation area in the green band using a proportion b of the difference between the NIR and Red bands. We then use the conventional IHS method to fuse the MS and Pan bands. The enhancement is accomplished only for the region where the NDVI is superior to **a preset** positive value a. We have tested a large number of images to select the value of the proportion b. In our experiments, for IKONOS a value of 0.4 for b gave best results in terms of fused image quality. For QuickBird the best fused results were achieved with b having value of 0.2. For a, we have used a value of 0.1.

Fig. 2 shows the proposed method described by the following steps:

1. Given the NIR and the R bands, calculate the NDVI index by using (1).
2. For any pixel (i,j) compute the enhanced green band ($G_{Boosted}$) using (2) :

If $NDVI(i,j) > a$ then

$$G_{Boosted}(i,j) = G(i,j) + b \times (NIR(i,j) - R(i,j)) \qquad (2)$$

else $G_{Boosted}(i,j) = G(i,j)$

3. The IHS transform is then applied on the R, B and $G_{Boosted}$.

4. The enhanced H and S are used with the Pan to get the enhanced multispectral RGB image (**MS^*_{RGB}**), by use of the inverse IHS transform. We then subtract the amount added in (2), only for the enhanced pixels, from the green band.

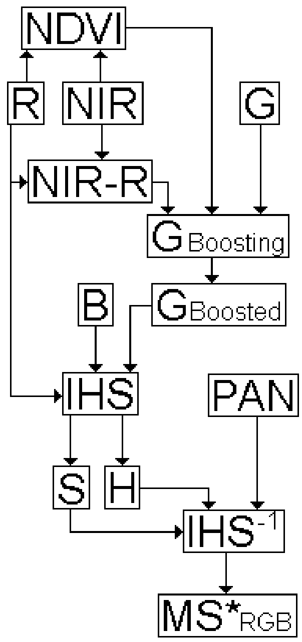

Fig. 2 Proposed fusion technique.

To evaluate the performance of our proposed approach, we present in the next section some indices for quality assessment.

IV. Quality Assessment of Fusion Products

The quality assessment of Pan-sharpened MS images is a difficult task. Even when spatially degraded MS images are processed for Pan-sharpening, so that reference MS images are available for comparisons, assessment of fidelity to the reference requires computation of several indices. Examples of indices are the band-to-band correlation coefficient (CC), the Bovik's index (Q_0) and the bias in the mean.

The bias refers to the difference in radiance between the means of the original and fused images.

The Bovik's image quality index Q_0 was introduced by Wang and Bovik in [10]. It is used to quantify the structural distortion between two images, one of them being the reference image and the other the distorted one. In fact, the value Q_0 is a measure for the similarity of images and takes values between -1 and 1. Note that Q_0 can be decomposed to three coefficients: the first is the correlation coefficient, the second component corresponds to a kind of average luminance distortion and it has a dynamic range of [0;1] (assuming nonnegative mean values). The third factor measures a contrast distortion and its range is also [0; 1]. The maximum value $Q_0 = 1$ is achieved when the two images are identical.

In addition to the CC, bias and Q_0 indices the following parameters are used to estimate the global spectral quality of the fused images [9].

We expressed the index of the relative average spectral error (RASE) as a percentage. This percentage characterizes the average performance of the image fusion in the considered spectral bands

$$RASE = \frac{100}{M}\sqrt{\frac{1}{N}\sum_{i=1}^{N} RMSE^2\left(B_i\right)} \tag{3}$$

Where M is the mean radiance of the N spectral bands (B_i) of the original MS bands, and $RMSE$ is the root mean square error computed by using the following expression:

$$RMSE^2\left(B_i\right) = bias^2\left(B_i\right) + SD^2\left(B_i\right) \tag{4}$$

Where SD is the standard deviation.

In the fusion, the index of the "erreur relative globale adimensionnelle de synthèse (ERGAS)" (which means relative global adimensional synthesis error) is as follows:

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{i=1}^{N}\frac{RMSE^2\left(B_i\right)}{M_i^2}} \tag{5}$$

Where h is the resolution of the high spatial resolution image, l is the resolution of the low spatial resolution image, and M_i is the mean radiance of each spectral band involved in the fusion. The lower the value of the *RASE* and *ERGAS* indexes, the higher the spectral quality of the fused images.

V. Experimental Results

To illustrate the proposed fusion procedure with examples, two data were used for this experiment. The first one is an image scene on Mt. Wellington, Tasmania, Australia, taken by the IKONOS satellite sensor on January 2005. The image size is approximately 10000×10000 pixels. The second one is an image scene on the Kokilai Lagoon, a Marine Protected Area in Sri Lanka, taken by the QuickBird satellite sensor on April 2005. The image size is approximately 2600×3200 pixels. Before the image fusion, the multispectral images were co-registered to the corresponding panchromatic images and resampled to the same pixel sizes of the panchromatic images. Two small areas in these images are shown; the first one is mostly vegetation and the second one contains less vegetation. Their Pan images are shown in Fig. 3 (a) and Fig. 4 (a), and the original RGB images in Fig. 3 (f) and Fig. 4 (f), respectively.

For comparison purposes, three other IHS fusion methods have been tested. The first one is the classical IHS (Classic).

The second method (Tu), described in [6], is given in (6).

$$\begin{bmatrix} F(R) \\ F(G) \\ F(B) \end{bmatrix} = \begin{bmatrix} R + Pan - (R + 0.75 * G + 0.25 * B + NIR)/4 \\ G + Pan - (R + 0.75 * G + 0.25 * B + NIR)/4 \\ B + Pan - (R + 0.75 * G + 0.25 * B + NIR)/4 \end{bmatrix} \quad (6)$$

The third method (Choi) is given in [3] by the following formulas (7):

$$\begin{bmatrix} F(R) \\ F(G) \\ F(B) \end{bmatrix} = \begin{bmatrix} Pan - \dfrac{(Pan - (R + G + B + NIR)/4)}{4} + (R - I) \\ Pan - \dfrac{(Pan - (R + G + B + NIR)/4)}{4} + (G - I) \\ Pan - \dfrac{(Pan - (R + G + B + NIR)/4)}{4} + (B - I) \end{bmatrix} \quad (7)$$

A. Visual Analysis

As shown for the test site in Fig. 3, most of the area is covered by green vegetation. The fusion results are shown in Fig. 3 (b-e).

Obviously, the fused image generated by classical IHS suffers from significant color distortion. By including the NIR band, the color distortion of the fused image obtained by the rest of methods is mitigated. Furthermore, the fused image achieved by the new method provides the highest spectral similarity to the original color image in Fig. 3 (f). The spatial and the spectral resolutions of the initial MS images appear to have been enhanced. That is, the results of the fusion contain structural details of the Pan image's higher spatial resolution and rich spectral information from the MS images.

Moreover, compared with the results of the fusion obtained by the other tested methods, the results of the proposed method have better visual accuracy.

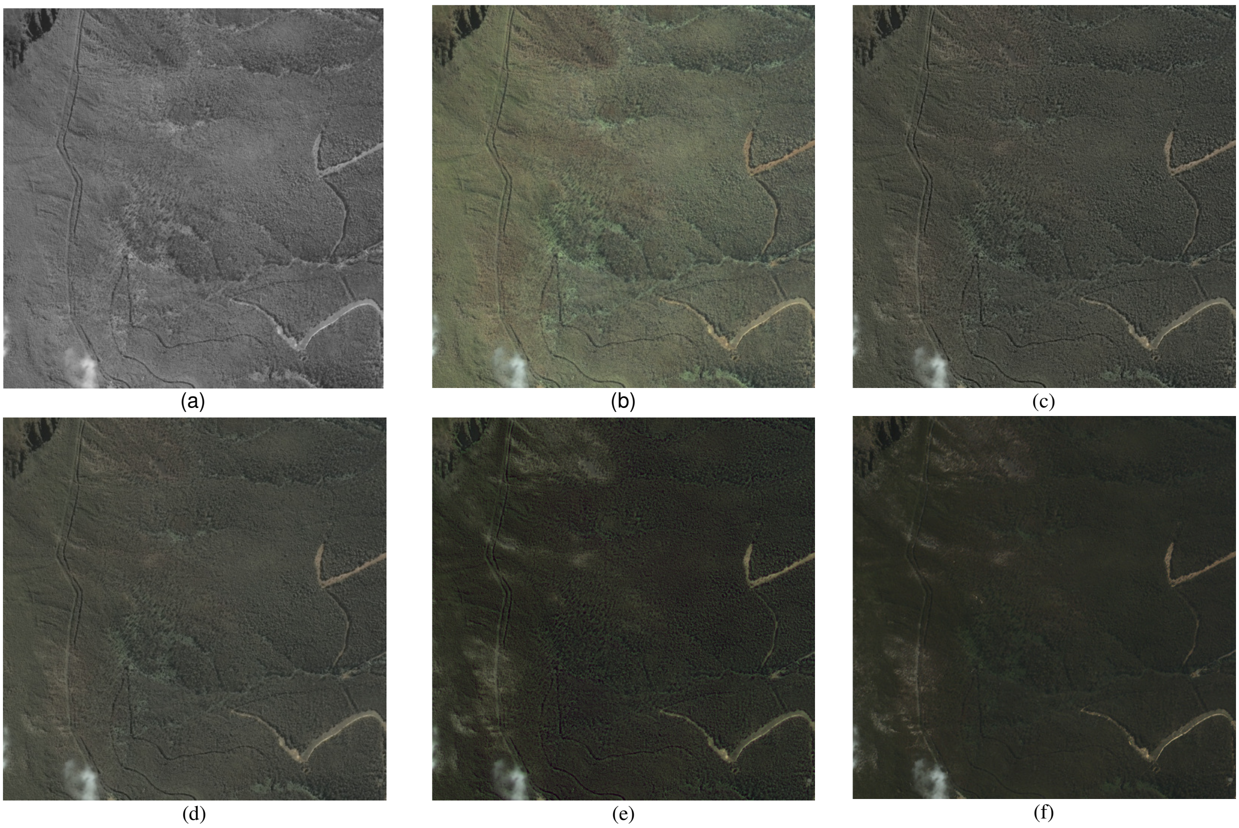

Fig. 3 IKONOS test region: (a) Pan image. (b) Classic IHS. (c) TU fused result. (d) CHOI fused result. (e) Proposed approach. (f) Original MS image.

For further verification, the test area in Fig. 4 (f) is used. This latter image includes more complicated land covers, such as bare soil, and green vegetated areas.

For QuickBird, the fusion results are displayed in Fig. 4 (b-e). Again, those figures show the same concluding remarks as those corresponding to Fig. 3.

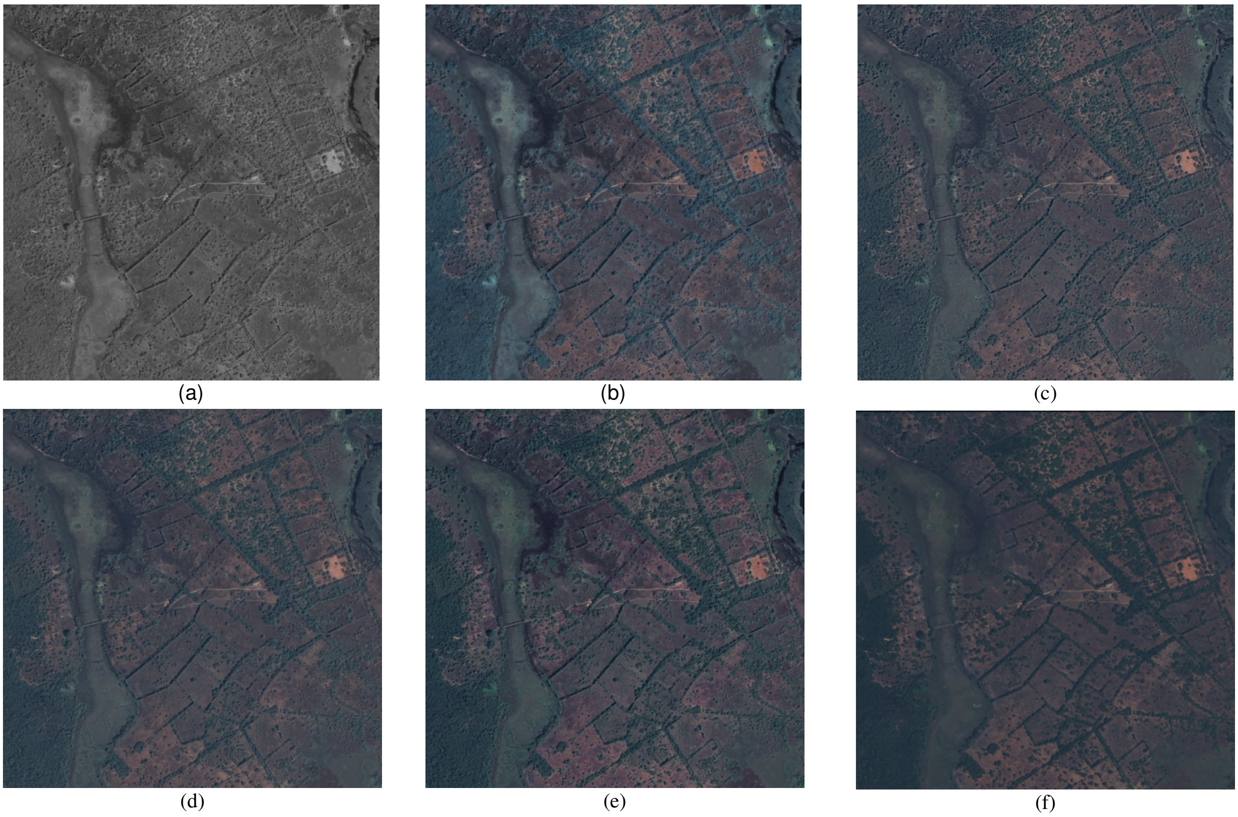

Fig. 4 QuickBird test region: (a) Pan image. (b) Classic IHS. (c) TU fused result. (d) CHOI fused result. (e) Proposed approach. (f) Original MS image.

B. Quantitative Analysis

In addition to visual analysis, we conducted a quantitative analysis. In order to assess the quality of the fused images in terms of CC, Q_0, bias, RASE and ERGAS. We created spatially degraded Pan and MS images derived from the original ones. They have a resolution of 1 and 4 m, respectively. Then, they were synthesized at a 1m resolution and compared to the original MS images.

Using these factors, Tables I and II compare the experimental results of image fusion for the two tested regions with the four methods.

The obtained results show that the new method provides better fusion in terms of bias, RASE and ERGAS for the two tested regions. In general, the larger vegetation area is, the better results are obtained.

TABLE I

A COMPARISON OF IMAGE FUSION BY CLASSIC IHS, TU METHOD, CHOI METHOD AND THE PROPOSED METHOD FOR IKONOS TEST REGION

	Band	Classic	TU	CHOI	Proposed
CC	R	0.5521	0.6846	0.7321	**0.8601**
	G	0.5065	0.6794	**0.7271**	0.7139
	B	0.4822	0.5888	0.6419	**0.8546**
Q_0	R	0.2667	0.3666	0.4317	**0.6273**
	G	0.2352	0.3531	**0.4203**	0.3932
	B	0.1680	0.2192	0.2668	**0.4938**
Bais	R	0.2093	0.0981	0.1004	**0.0011**
	G	0.2166	0.0981	0.1004	**0.0001**
	B	0.1791	0.0981	0.1004	**0.0008**
RASE		271.3365	194.6752	193.7181	**99.8919**
ERGAS		30.9925	16.1258	15.9635	**4.3290**

TABLE II

A COMPARISON OF IMAGE FUSION BY CLASSIC IHS, TU METHOD, CHOI METHOD AND THE PROPOSED METHOD FOR QUICKBIRD TEST REGION

	Band	Classic	TU	CHOI	Proposed
CC	R	0.8176	0.8354	0.8614	**0.8941**
	G	0.6614	0.7397	**0.7767**	0.7381
	B	0.3716	0.5311	0.5736	**0.6209**
Q_0	R	0.7183	0.7194	0.7592	**0.8228**
	G	0.5643	0.6306	**0.7116**	0.6143
	B	0.2848	0.4025	**0.4859**	0.4650
Bais	R	0.0435	0.0464	0.0385	**0.0218**
	G	0.0492	0.0464	0.0385	**0.0261**
	B	0.0556	0.0464	0.0385	**0.0257**
RASE		107.9817	101.1529	92.1941	**86.6141**
ERGAS		6.9703	6.1965	5.1628	**4.5098**

VI. CONCLUSION

We have presented a new approach for image fusion based on the IHS method. Due to non ideal spectral responses of the IKONOS and QuickBird imagery, the original IHS technique often produces color distortion problems in fused images, especially on vegetated areas. The proposed method boosts the Green band, by using NIR and Red bands information, in the vegetation area in order to amplify the Intensity grey values. The fusion of the Pan and enhanced Intensity image produces a reduced distortion in MS color images. Visual and quantitative analyses of experimental results show that the proposed method gives the best fused images in terms of CC, Q_0, Bias, RASE and ERGAS when the area of the manipulated images is mostly vegetation. Moreover, even when the image contains less vegetation, the results obtained by the proposed technique are still satisfactory and promising.

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