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Research paper

Influence of the weights in IHS and Brovey methods for pan-sharpening WorldView-3 satellite images

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Abstract

The purpose of this paper is to investigate the impact of weights in pan-sharpening methods applied to satellite images. Indeed, different data sets of weights have been considered and compared in the IHS and Brovey methods. The first dataset contains the same weight for each band while the second takes in account the weighs obtained by spectral radiance response; these two data sets are most common in pan-sharpening application. The third data set is resulting by a new method. It consists to compute the inertial moment of first order of each band taking in account the spectral response. For testing the impact of the weights of the different data sets, WorlView-3 satellite images have been considered. In particular, two different scenes (the first in urban landscape, the latter in rural landscape) have been investigated. The quality of pan-sharpened images has been analysed by three different quality indexes: Root mean square error (RMSE), Relative average spectral error (RASE) and Erreur Relative Global Adimensionnelle de Synthèse (ERGAS).

Keywords: *World View-3; Pan-Sharpening; Spectral Radiance Response; His; Brovey*.

1. Introduction

The passive sensors recording the intensity of the reflected electromagnetic energy coming from the Sun or emitted by the Earth and the optical sensors, in relation to the spectral range, can acquire in panchromatic (PAN) and multispectral (MS) bands [1].
Panchromatic data from Remote-Sensing systems have a smaller pixel size, and a greater width of the acquisition band compared to those multispectral. To avoid an unfavourable signal/noise ratio, decreasing the width of the acquisition band, it is necessary widening the size of the pixels to the ground in order to intercept a greater amount of energy reflected. To overcome the physical limitations of available sensors, an extensive number of data fusion methods has been proposed in the literature [2]. The pan-sharpening (branch of data fusion) allows to fuse the higher geometric resolution of the panchromatic images with the spectral resolution of multispectral images [3]. In this way, each low resolution multispectral image (LRMI) is transformed into high resolution multispectral image (HRMI).
In literature, many pan-sharpening methods have been studied and developed e.g.: Brovey, Weighted Brovey, Gram Schmidt, Intensity-Hue-Saturation (IHS), Fast IHS, Multiplicative, Principal Component Analysis (PCA), Simple Mean, high-pass filtering (HPF), Price, Generalized Laplacian pyramid (GLP) and Zhang [4, 5, 6].
Actually, the choose of a method, the image segmentation and estimation of the sharpening or fusion performance are still an open problem. Because the aim of this paper is to investigate the behavior of the quality of the image varying the weights of several bands, a special focus on IHS and Brovey is explained. In particular, in relation to the adopted weight data set, different quality of the pan-sharpened images may be obtained. In addition, this dataset of the weights varies with the type of satellite image used.
In this paper, different weights are applied to WorldView-3 (WV-3) satellite imageries.

2. Data and methods

Nowadays, the pipeline for the analysis of the pan-sharpened images follows a more or less standardized workflow. In fact, depending on the type of transformation employed, a different pipeline is obtained.
According to Baronti et al. [7] the majority of image fusion methods can be divided into two main classes:

- Techniques that employ linear space-invariant digital filtering of the panchromatic image to extract the spatial details;
- Techniques that yield the spatial details as pixel difference between the panchromatic image and a nonzero-mean component obtained from a spectral transformation of the MS bands, without any spatial filtering of the former.

In this paper, considering the IHS and Brovey methods for pan-sharpening images, all the process steps of satellite images, can be summarized as shown in the figure 1.
As shown in the figure 1, at the end of the single method, a quantitative analysis is conducted, in order to measure the similarity between images.

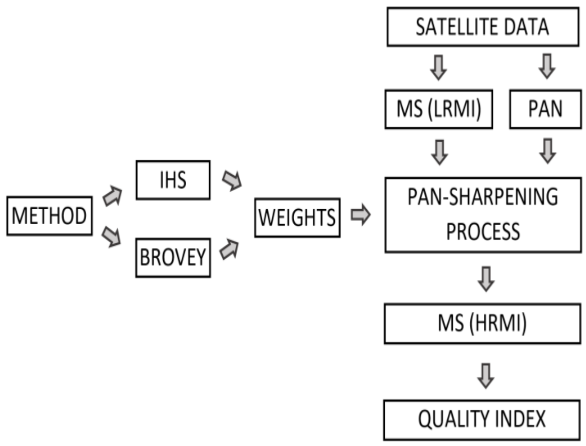

Fig. 1: Pipeline for Pan-Sharpening Process and Analysis.

2.1. WorldView-3 images

The latest generation of commercial satellite sensors provides images with a very high geometric resolution (VHR). An example of the VHR commercial satellite is WV-3. Launched on August 13, 2014, it joined the other Digital Globe satellites in orbit, i.e. GeoEye-1 and WorldView-2 supplying panchromatic images with cell size 0.5 m and multispectral ones with cell size 2.0 m [8, 9, 10]. WV-3 collects data with nominal ground sample distance of 0.31 m (panchromatic), 1.24 m (multispectral) and 3.7 m (SWIR) at nadir configuration. However, the commercial images are resampled to 0.3 m (panchromatic), 1.2 m (multispectral) and 7.5 m (SWIR).
From the radiometric point of view, WV-3 acquires 11-bit data in 9 spectral bands covering panchromatic and multispectral bands. The single-wavelength band for a PAN image is 0.45–0.90 μm. The MS images have eight wavelength bands: Coastal (B1: 400-450 nm), Blue (B2: 450–510 nm), Green (B3: 510-580 nm), Yellow (B4: 585-625 nm), Red (B5: 630-690 nm), Red Edge (705-745 nm), NIR1 (B7: 770-895 nm), NIR2 (860-1040 nm). An additional shortwave infrared (SWIR) sensor acquires 14-bit data in eight bands covering the 1100 to 2500 nm spectral region (Figure 2).

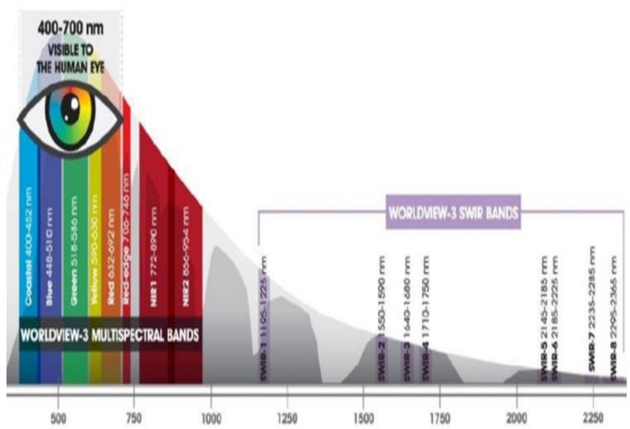

Fig. 2: Electromagnetic Spectrum Worldview-3 (Image Taken from Digital globe Website).

2.2. IHS pan-sharpening method

Introduced by Carper [1], the IHS transform separates spatial (Intensity) and spectral (Hue and Saturation) information from a standard RGB image [12]. As it is known, the intensity is brightness of the image; hue is the dominant or average wavelength of the light contributing to the colour (colour perception) and saturation represent to purity of the colour [13]. In the IHS method, the component Intensity can be defined as [14]:

$$I = \frac{\sum_{k=1}^{n} w_k \cdot B_k}{\sum_{k=1}^{n} w_k} \quad (1)$$

Where:
w_k Weight of the k-th band;
B_k Digital Number (DN) of the k-th band.

By adding to each initial image multispectral (resampled) the difference between the Intensity and the panchromatic value, it is possible to obtain the multispectral components with the same geometric resolution of PAN data using the equation:

$$[B_k]_{HRMI} = [B_k]_{LRMI} + \delta \quad (2)$$

Where

$$\delta = [PAN] - [I] \quad (3)$$

If the weights assume the same value, this transformation is called IHS, while if they assume different values, this processing is called Fast-IHS [15, 16].

2.3. Brovey pan-sharpening method

The transformation of Brovey (BT) allows to obtain a multispectral image of greater detail by exploiting the idea that the spatial details are modulated into the MS images by multiplying the MS images by the ratio of the PAN [17].
This transformation was developed to increase the contrast in low and high ends of histogram of an image and produce visually appealing images. The mathematic formulation of this method is [18]:

$$fusion_k = \frac{PAN}{Syn_p} \cdot MS_K \quad (4)$$

Where
$fusion_k$ Fused k-th band;
MS_K MS k-th band (lower resolution);
Syn_p Synthetic band;
PAN PAN band (higher resolution).

The synthetic image can be obtained in two ways. In the first case, it is obtained as the average of the multispectral bands that are included in panchromatic one [3], [19]:

$$Syn_p = \frac{\sum_{k=1}^{n} MS_k}{n} \quad (5)$$

In the second case, introducing (different) band weights, it is possible to obtain the following relation of image fused:

$$Syn_p = \frac{\sum_{k=1}^{n} w_k \cdot MS_k}{\sum_{k=1}^{n} w_k} \quad (6)$$

In this latter case, this transformation is called Weighted Brovey.

2.4. Spectral radiance response and first moment of inertia of spectral radiance response

A method to obtain weights is to analyse the spectral radiance response. It is defined as the ratio of the number of photo-electrons measured by the instrument system, to the spectral radiance at a particular wavelength present at the entrance to the telescope aperture. It includes not only raw detector quantum efficiency, but also transmission losses due to the telescope optics and filters. The spectral radiance response for each band is normalized by dividing by the maximum response value for that band to arrive at a relative spectral radiance response [20]. According to Belfiore et al. [21], it is possible to calculate the minimum value of the intercepted radiance (IntRad) between the panchromatic and multispectral bands for every wavelength interval; the IntRad for each

band is divided for the IntRad sum of all bands in order to obtain the “standard weights” for the pan-sharpening methods.
In the Worldview-3 images, the weights assume the value indicated in the table 1.

Table 1: Weights Standard for Worldview-3 Multispectral Images

Band	B_1	B_2	B_3	B_4	B_5	B_6	B_7
weight	w_1 0.005	w_2 0.142	w_3 0.209	w_4 0.144	w_5 0.234	w_6 0.157	w_7 0.116

As can be seen from Table 1, there is not reported the weight for NIR2 band. This is justified because the NIR2 curve does not intersect the panchromatic curve.
A new method that takes into account the greater response of some bands than others has been developed. It consists in the compute the relative first moment of inertia (or well known as first moment of area) (Ms) of each band that is the multiplication of the area contained in panchromatic band for the relative spectral response height:

$$Ms = A(k) \cdot \bar{y}(k) \quad (7)$$

Where:

$A(k)$ Area of single band (k) contained in panchromatic boundary;

$\bar{y}(k)$ Distance from the centroid of relative band (k) area contained in panchromatic boundary to the horizontal axes.

In this way, different weights are attributed taking into account the spectral response of all bands, so the red component has got a greater weight while the blue has a lower one.
A graphical representation of elements, such as centroids and distance from each centroid to the abscissa axis measured on Spectral Response of WV-3, is shown in figure 3.

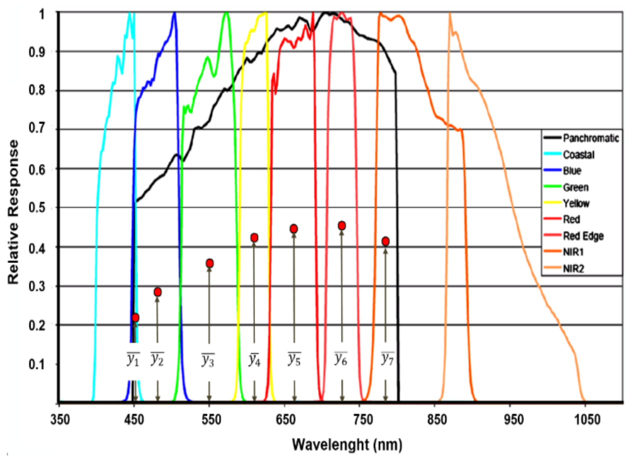

Fig. 3: Spectral Response of WorldView-3 Panchromatic and Multispectral Sensors with Representation of the Centroid (Red Dots) of Each Band Area Contained in Panchromatic Boundary and the Relative Height.

Therefore, normalizing the values of the moment of inertia it is possible to obtain the following new weight dataset (table 2).

Table 2: Inertial Weights for Worldview-3 Multispectral Images

Band	B_1	B_2	B_3	B_4	B_5	B_6	B_7
weight	w_1 0.005	w_2 0.104	w_3 0.198	w_4 0.151	w_5 0.251	w_6 0.178	w_7 0.113

2.5. Quality indexes

Quality indexes have been defined in order to compare the pan-sharpening images with the initial ones. In this paper, three indices were considered: RMSE, RASE and ERGAS.
Root mean square error (RMSE) index is computed using the formula [22]:

$$RMSE(band_k) = \sqrt{BIAS_k^{\,2} + \sigma_k^{\,2}} \quad (8)$$

Where

BIAS Difference between the mean values of the input LRMI and the output one (HRMI);

σ_k Standard deviation of the difference images LRMI and HRMI.

Relative average spectral error (RASE) index characterizes the average performance of a method in the considered spectral bands [18]. This index is calculated including all multispectral images by following formula [23]:

$$RASE = \frac{100}{M}\sqrt{\frac{1}{n}\sum_{i=1}^{n} RMSE_i^2} \quad (9)$$

Where M is the mean value of Digital Numbers (DNs) of the n input images (MS).
The ERGAS (Erreur Relative Global Adimensionnelle de Synthèse), also indicated as a dimensionless Global Relative Error in Synthesis [24] is another index to evaluate the quality of the pan-sharpening. Introduced by Wald [25], it is calculated using the following formula:

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N_{Bands}}\sum_{k=1}^{N_{Bands}}\left(\frac{RMSE(Band_K)}{MS_k}\right)^2} \quad (10)$$

Where

h Spatial resolution of PAN image;

l Spatial resolution of MS image;

N_{Bands} Number of bands of the HRPI image;

MS_k Mean radiance value of the k-th band of MS image.

The good image quality derived from pan-sharpening is characterized by low values of RMSE, RASE and ERGAS index. In the ideal transformation, these indexes should be close to zero [26].

3. Application of the pan-sharpening methods

In order to verify the quality of several pan-sharpening methods, using IHS and Brovey methods, the following datasets of weights have been investigated:

- Standard weights (SW) (table 1);
- Inertial weights (IW) (table 2);
- Equal weights (EW) (0.142 for each of seven bands).

Two different area studios have been taken in account; the characteristic parameters of the satellite images are reported in the table 3.

Table 3: Characteristic Parameters of the WorldView-3 Images

		Baden- Wurttemberg (Germany)	Tripoli (Libya)
Dimension	MS	1479 x 2608	703 x 997
(pixel)	PAN	5913 x 10429	2812 x 3986
Acquisition date		2015/06/06	2016/03/08
Acquisition time		10:35:25	10:12:13

The choice of two different scenarios (urban and rural landscape) allows to generalize as closely as possible the impact that weight dataset involves in the quality of the image pan-sharpening (figure4).
The satellite images are courteously supplied by Digital Globe as product samples available for download.
The quality indexes (RMSE, RASE and ERGAS) obtained in the two-investigated landscapes, can be summarized in the following tables (Tables 4 and 5).

Fig. 4: Multispectral LRMS Scene of Worldview3 in RGB (5-3-2 Composite Bands): (Left Image) Urban Area (Libya) - Projection: Transverse Mercator; WGS 1984 UTM Zone 33N; (Right Image) Rural Area (Germany) - Projection: Transverse Mercator; WGS 1984 UTM Zone 32N.

Table 4: Quality Indexes Obtained from Urban Scenario (Libya)

Methods	Band	Standard Weights			Inertial Weights			Equal Weights		
		RMSE	RASE	ERGAS	RMSE	RASE	ERGAS	RMSE	RASE	ERGAS
IHS	1	188.525	41.719	9.189	195.975	42.373	9.263	214.168	46.837	9.626
	2	192.735			194.991			215.954		
	3	192.920			195.165			216.015		
	4	192.612			194.919			215.928		
	5	192.834			195.092			215.981		
	6	192.420			194.765			215.861		
	7	192.794			195.061			215.966		
BROVEY	1	137.022	41.071	8.710	144.970	42.220	8.872	137.292	48.785	9.428
	2	180.846			188.281			208.268		
	3	235.819			242.445			284.521		
	4	191.022			194.905			227.426		
	5	178.127			182.102			219.542		
	6	177.170			180.353			213.061		
	7	209.122			213.803			254.631		

The values of quality indexes have been obtained by raster calculator of ArcMap© and suitable algorithm developed in Matlab© software.

A visual comparison of the results of pan-sharpened data using diverse methods and weights is shown in the figure 5 and 6.

In order to display more detail, a subset of the two VW-3 images has been chosen.

In these images, it is possible to note that in all scenarios investigated, the pan-sharpening techniques and weights datasets adopted have improved the resolution of fused image.

Table 5: Quality Indexes Obtained from Rural Scenario (Germany)

Methods	Band	Standard Weights			Inertial Weights			Equal Weights		
		RMSE	RASE	ERGAS	RMSE	RASE	ERGAS	RMSE	RASE	ERGAS
IHS	1	16.707	5.571	2.082	16.937	5.648	2.106	24.680	8.210	3.401
	2	16.747			16.974			24.693		
	3	16.783			17.013			24.707		
	4	16.760			16.994			24.703		
	5	16.782			17.013			24.701		
	6	16.760			16.994			24.700		
	7	16.784			17.016			24.705		
BROVEY	1	12.636	7.149	1.639	13.018	7.283	1.665	16.554	10.661	2.280
	2	10.869			11.141			13.977		
	3	13.717			13.966			17.779		
	4	12.849			13.013			16.139		
	5	11.383			11.489			13.816		
	6	20.637			20.938			29.800		
	7	45.291			46.171			71.245		

Fig. 5: Particular of Urban Images (Bands: 5, 3, 2): (A) LRMS; (B) IHS SW; (C)IHS IW; (D) IHS EW; (E) Brovey SW; (F) Brovey IW; (G) Brovey EW.

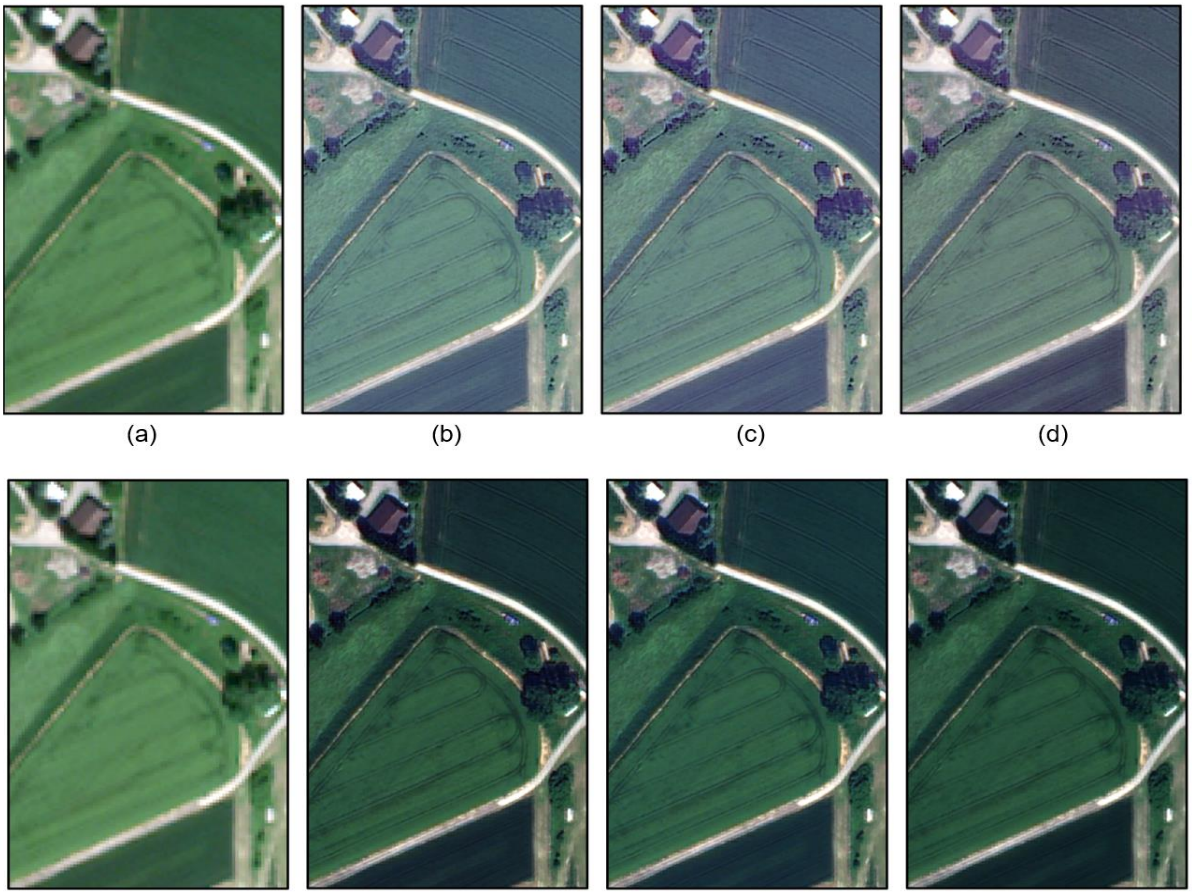

Fig. 6: Particular of Rural Images (Bands: 5, 3, 2): (A) LRMS; (B) IHS SW; (C)IHS IW; (D) IHS EW; (E) Brovey SW; (F) Brovey IW; (G) Brovey EW.

4. Conclusions

In this paper, the use of different weights and pan-sharpening methods have led diverse quality of the HRMIs in each scenario investigated. In general, the analysis of quality indexes in the different scenarios has shown highest values of RMSE, RASE and ERGAS indexes for urban landscape.
As concerning the pan-sharpening images obtained with the inertial weight data set, the quality indexes attest this data set led a greater adaptation than the equal weights in each scenario, despite it was not the better in the two tested scenarios. In fact, standard weight data set supplies better results, but inertial weight one is comparable with it in order to the performance level. Even if, according to Snehmani et al [27], no single pan sharpening method can be considered the best, introducing different weights for each band of WV-3 images in IHS and Brovey method's better results are achieved.
Therefore, the good quality and high geometric resolution (pixel 30 cm) of the multispectral pan-sharpened images allow a better representation of the territory. In addition, the multispectral pan-sharpened images can be used as a basic information layer for civil engineering applications, such as the design of roads, railways, aqueducts, etc.

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