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WorldView-2 pan-sharpening by minimization of spectral distortion with least squares

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Abstract : Although the intensity-hue-saturation (IHS) method for pan-sharpening has a spectral distortion problem, it is a popular method in the remote sensing community and has been used as a standard procedure in many commercial packages due to its fast computing and easy implementation. Recently, IHS-like approaches have tried to overcome the spectral distortion problem inherited from the IHS method itself and yielded a good result. In this paper, a similar IHS-like method with least squares for WorldView-2 pan-sharpening is presented. In particular, unlike the previous methods with three or four-band multispectral images for pan-sharpening, six bands of WorldView-2 multispectral image located within the range of panchromatic spectral radiance responses are considered in order to reduce the spectral distortion during the merging process. As a result, the new approach provides a satisfactory result, both visually and quantitatively. Furthermore, this shows great value in spectral fidelity of WorldView-2 eight-band multispectral imagery.

Key Words : Pan-sharpening, intensity-hue-saturation transform, least squares, WorldView-2 eight band imagery.

1. Introduction

Most high-resolution satellites provide a panchromatic (PAN) image and multispectral (MS) images with different spatial and spectral resolutions due to the technical limitations of satellite imaging systems (Zhang, 2004). Pan-sharpening, which is the fusion of a PAN image with a high spatial and low spectral resolution and MS images with a low spatial and high spectral resolution, is therefore a very useful technique in many remote sensing applications that require both high spatial and high spectral resolution, especially for GIS-based applications (Choi, 2006).

Among various pan-sharpening techniques, intensity-hue-saturation (IHS) fusion methods have been used in many commercial packages because they are fast and can be easily implemented. However, the IHS method distorts color information during the fusion process (Kim *et al.*, 2007; Choi *et al.*, 2007a). A new IHS-like method with least squares is introduced for WorldView-2 pan-sharpening to reduce this spectral distortion. WorldView-2, which was launched in October 2009, is the first high-resolution eight-band MS commercial

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satellite. Operating at an altitude of 770 km, WorldView-2 provides a 46 cm PAN resolution and a 1.84 m MS resolution. In this paper, six bands of an eight-band MS image located within the range of PAN spectral radiance responses are used with satisfactory results to reduce the spectral distortion of an IHS-like method.

2. Intensity-hue-saturation method

The IHS transform converts a color image from red, green, and blue (RGB) space into an IHS color space. The intensity component in the IHS space is replaced with a high-resolution PAN image and then transformed back to the original RGB space together with the previous hue and saturation, resulting in IHS pan-sharpened images. The IHS method can be formulated and simplified by the following procedure (Tu *et al.*, 2004):

$$\begin{bmatrix} F(R) \\ F(G) \\ F(B) \end{bmatrix} = \begin{bmatrix} R + (PAN - I) \\ G + (PAN - I) \\ B + (PAN - I) \end{bmatrix} \quad (1)$$

where I is the intensity component and F(X) is the pan-sharpened image of the band, for X= R, G, and B, respectively.

Equation (1) states that the pan-sharpened image $[F(R), F(G), F(B)]^T$ can be easily obtained from the original image $[R, G, B]^T$ simply by using addition operations. That is, the IHS method can be implemented efficiently by this procedure. Aside from its fast computing capability for the fusion of images, this method can extend a traditional three-order transformation to an arbitrary order. However, the problem with the IHS method is that spectral distortion may occur during the merging process. In (1), the large difference between the values of PAN and I appears to cause the large spectral distortion of the pan-sharpened images. Indeed, this difference (PAN – I) causes the altered saturation component in the RGB-IHS conversion model (Tu *et al.*, 2001; Choi, 2007b).

3. WorldView-2 Pan-sharpening

When IHS-like methods are used in high-resolution satellite imagery, there is a significant color distortion, due primarily to the range of wavelengths in a PAN image. For example, IKONOS PAN has an extensive range of wavelengths from visible to near-infrared (NIR). This difference obviously induces the color distortion problem in the IHS procedure as a result of the mismatches; that is, the PAN and I are spectrally dissimilar. To minimize the radiance differences between PAN and I, Tu *et al.* (2004) gave consideration to the following equation when they introduced the NIR band with spectral adjustment applied to the I component:

$$I = \frac{R + a * G + b * B + NIR}{3}, \quad (2)$$

where a and b are weighting parameters defined in view of the fact that the spectral response of the PAN does not cover that of the blue and green bands. However, the values of these parameters were estimated experimentally after pan-sharpening of 92 IKONOS images with covering different areas.

The WorldView-2 satellite carries an imaging instrument that contains a high-resolution PAN band and eight lower spatial resolution MS bands. As with the IKONOS PAN, WorldView-2 PAN (as shown Fig.1) has an extensive range of wavelengths from blue to near-infrared 1 (NIR1). The extensive range obviously induces the color distortion problem in the IHS-like method. This problem of Worldview-2 pan-sharpening can be overcome by using the proposed IHS-like method, which is extended with least squares as follows:

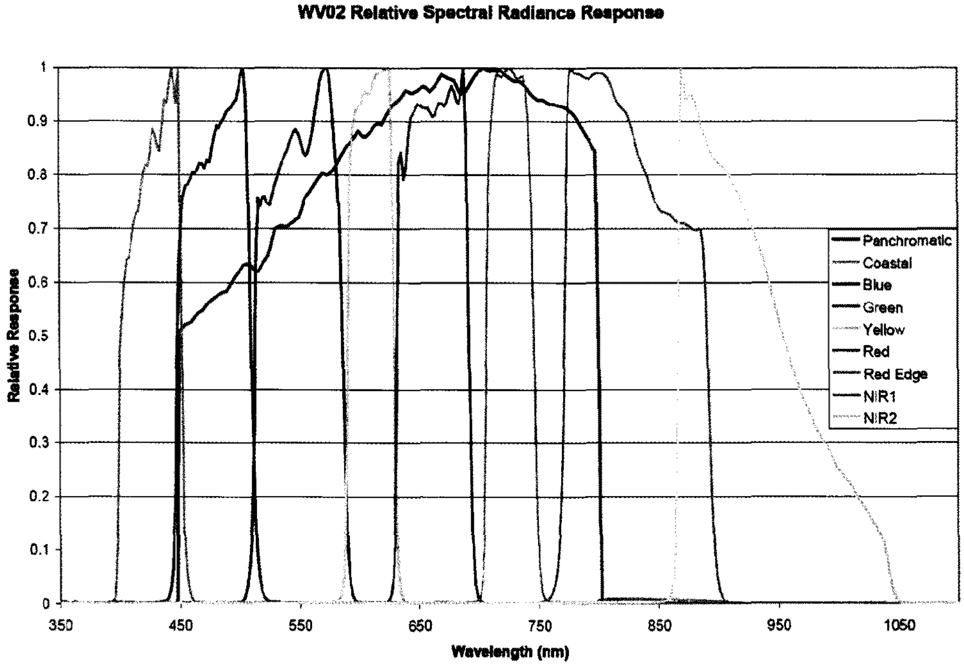


Fig. 1. Spectral response of the WorldView-2 PAN and MS imagery.

$$F(MS_i) = MS_i + (PAN - I_{new}) \quad \text{with} \min_{x_i} \| PAN - I_{new} \|, \qquad (3)$$

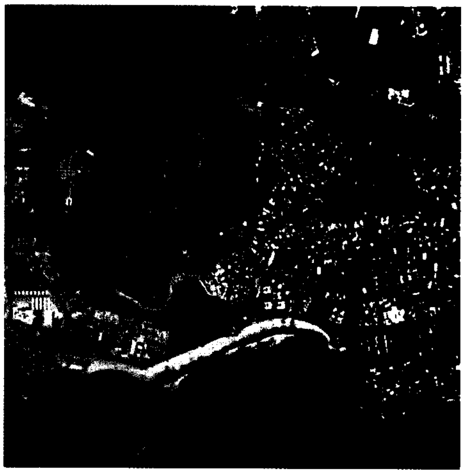
where $I_{new} = \sum_i x_i * MS_i$, $i = 1, ..., 6$, and MS_i is a band that corresponds to a WorldView-2 six-band MS image located within the spectral response of a WorldView-2 PAN image. Furthermore, in contrast to the empirical approach of Tu *et al.* (2004), the least squares method is directly used in this procedure to estimate the x_i value of the I_{new} component.

4. Experimental results

The methods are evaluated in terms of three different band-independent quality indexes: namely, Q4, ERGAS (*erreur relative globale adimensionelle de synthese*), and the Spectral Angle Mapper (SAM) (Stathaki, 2008). The first two indexes account for the spectral and radiometric distortion of pan-sharpened MS images, whereas the last index is solely a measure of spectral quality. The datasets were degraded by four in accordance with the protocol proposed in (Wald *et al.*, 1997), and the statistics represent the pan-sharpened data and the original data. Table 1 reports on the values of three global indexes for the WorldView-2 data set at a reduced resolution; that is, by merging the 2 m-PAN data with the 8 m-MS data to obtain 2 m-MS fused images, which are subsequently compared to the original 2m-MS images. The proposed IHS-like method has the best performance (lower ERGAS and SAM, and higher Q4).

Fig. 2. shows WorldView-2 pan-sharpened 50 cm-MS images. The spectral distortion apparently appears in IHS pan-sharpened images. However, the pan-sharpened MS images by all the IHS-like methods are acceptable for visual analysis when compared with the original 2m-MS images.

(a) Original color image (512 × 512)



(b) IHS (2048 × 2048)

(c) Generalized IHS 4-band (2048 × 2048)

(d) Generalized IHS 6-band (2048 × 2048)

(e) Proposed (2048 × 2048)

Fig. 2. Visual results of WorldView-2 pan-sharpening.

Table 1. Quantitative results of WorldView-2 pan-sharpening

Methods \ Quality Indexes	Q4	ERGAS	SAM
IHS, where I = (B + G + R)/3	0.7997	7.8281	5.0115
GIHS 4-band, where I = (B + G + R + NIR1)/4	0.9015	5.9486	2.4754
GIHS 6-band, where I = (B + G + Y + R + RE + NIR1)/6	0.9052	5.3166	2.3101
Proposed I_{new}, I_{new}, = $x_1 * B + x_2 * G + x_3 * Y + x_4 * R + x_5 * RE + x_6 * NIR1$	<u>0.9146</u>	<u>4.9792</u>	<u>1.7495</u>

5. Conclusion

Through the incorporation of least squares into an IHS-like method, this paper presents a new approach to WorldView-2 pan-sharpening. In particular, six bands WorldView-2 MS multispectral images located within the range of panchromatic spectral radiance responses are considered. The spectral quality of the resulting images is examined by means of Q4, ERGAS, and SAM. The proposed method produces satisfactory results, from both a visual and quantitative perspective. Furthermore, this shows great value in spectral fidelity of WorldView-2 eight-band MS imagery.

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