Fast panchromatic sharpening for high-resolution multi-spectral images

Jonghwa Lee and Chulhee Lee

Department of Electrical and Electronic Engineering, Yonsei University
134 Shinchon-Dong, Seodaemoon-Gu, Seoul, KOREA
Email: chulhee@yonsei.ac.kr Tel: (82-2) 2123-2779 Fax: (82-2) 312-4584

1. ABSTRACT

We present a fast and general panchromatic sharpening for fusing low-resolution multi-spectral images with a high-resolution panchromatic observation. For IKONOS imagery, both multi-spectral and panchromatic data are provided with spatial resolutions of 4 and 1 meter. In order to produce multi-spectral images with high spatial resolution same to panchromatic image, several fusion methods have been developed [1]-[6]. However, classical methods such as IHS [1-2], PCA [3] and Brovey transform often introduce severe color distortion due to injecting undesired low-pass component of panchromatic image. Recent methods employing the discrete wavelet transform (DWT) or the undecimated DWT [4] preserve good spectral information. However, it is not applicable to process a large volume of data due to memory requirement and computational cost. The high-pass filtering, Laplacian pyramid [5], and high-pass modulation (HPM) [6] methods provide good performance with minimized spectral distortion and low computational complexity. In this paper, we present a fast alternative of HPM with incorporating the modulation transfer function (MTF). The experimental results demonstrate that the proposed method produces high-quality fused image and outperforms existing fusion methods in terms of objective quality measures such as UIQI[7], Q4[8], RASE, and ERGAS[9].

2. METHODOLOGY

In this paper, we assume that a panchromatic image can be represented as a sum of low and high frequency components: $P^{\Omega} = P_L^{\Omega} + P_H^{\Omega}$ where P^{Ω} represents a panchromatic image with resolution index $\Omega \in \{LR, HR\}$, P_L^{Ω} represents a low frequency component of the panchromatic image, and P_H^{Ω} represents a high frequency component of the panchromatic image. For example, a high-resolution panchromatic image can be decomposed into two frequency components: $P^{HR} = P_L{}^{HR} + P_H{}^{HR}$. Analogously, low-resolution multi-spectral images can also be decomposed into two frequency components: $MS_{band(i)}^{LR} = MS_{L,band(i)}^{LR} + MS_{H,band(i)}^{LR}$ where $MS_{band(i)}^{LR}$ represents a low-resolution multi-spectral image with band index $band(i) \in \{R, G, B, NIR\}$ for IKONOS images. For IKONOS images, the ratio of pixel resolution of high-resolution and low-resolution images is 4:1. The high-pass modulation method [6] can be formulated to estimate high-resolution MS images ($\overline{MS}_{band(i)}^{HR}$) as follows:

$$\overline{MS}_{band(i)}^{HR} = P^{HR} \cdot \overline{MS}_{L,band(i)}^{HR} / \overline{P}_L^{HR} \tag{1}$$

where a low frequency component of the estimated high-resolution multi-spectral image ($\overline{MS}_{L,band(i)}^{HR}$) is an upsampled result of the original low-resolution multi-spectral image ($upsampling(MS_{band(i)}^{LR})$) and a low frequency component of the estimated high-resolution panchromatic image ($\overline{P}_L^{HR}$) is a result of cascade process of upsampling and downsampling to the original high-resolution panchromatic image. It is noted that HPM assumes the high frequency component of the estimated high-resolution MS images ($\overline{MS}_{H,band(i)}^{HR}$) is a scaled version of the high frequency component of panchromatic image ($\alpha \cdot \overline{P}_H^{HR} \approx \alpha \cdot (P^{HR} - \overline{P}_L^{HR})$) and the scaling factor is a local mean modulation ($\alpha = \overline{MS}_{L,band(i)}^{HR} / \overline{P}_L^{HR}$).

However, (1) requires four upsampling operations to estimate high-resolution multi-spectral images, one for $\overline{P}_L^{HR}$ and four for $\overline{MS}^{HR}_{L,band(i)}$. Efforts have been made to make accurate estimation of the modulation transfer function (MTF) for IKONOS sensors. Therefore, (1) can be re-formulated as follows:

$$\overline{MS}^{HR}_{band(i)}(x,y) \approx P^{HR}(x,y)\cdot(MS^{LR}_{band(i)}(x/4,y/4)+\delta^{HR}_{MS^{LR}_{band(i)}}(x,y))/(\overline{P}^{LR}(x/4,y/4)+\delta^{HR}_{\overline{P}^{LR}}(x,y)) \qquad (2)$$

where (x,y) specifies the spatial coordinates of high-resolution images, (x/4, y/4) specifies the spatial coordinates of low-resolution images, $\delta^{HR}_{MS^{LR}_{band(i)}}$ defines a local delta of $MS^{LR}_{band(i)}$ utilizing MTF, and $\delta^{HR}_{\overline{P}^{LR}}$ defines a local delta of $\overline{P}^{LR}$ utilizing MTF. Using (2), we don't need any upsampling operations, eliminating large memory requirement. The final multi-spectral image is estimated by adjusting mean values:

$$\overline{\overline{MS}}^{HR}_{band(i)} = \overline{MS}^{HR}_{band(i)} + \mu_{MS^{LR}_{band(i)}} - \mu_{\overline{MS}^{HR}_{band(i)}}$$

where $\mu_{MS^{LR}_{band(i)}}$ represents the mean of the original multi-spectral images and $\mu_{\overline{MS}^{HR}_{band(i)}}$ represents the mean of of $\overline{MS}^{HR}_{band(i)}$.

3. EXPERIMENTAL RESULTS

Experiments were conducted to evaluate the performance of the proposed method using the IKONOS images provided by (c)GeoEye. We compared the proposed method with six existing methods: IHS [1], fastIHS [2], PCA [3], undecimated DWT [4], GLP [5] and HPM [6]. Table I shows performance comparison. As can be seen in Table I, the proposed method provides better performance than the other fusion methods.

Table 1. Performance comparison.

Methods	UIQI[7]	Q4[8]	RASE	ERGAS[9]	CORR	Elapsed time
IHS[1]	0.581	0.635	10.25	1.921	0.631	2.844 s
fastIHS[2]	0.698	0.776	9.45	1.845	0.734	1.843 s
PCA[3]	0.665	0.727	9.10	1.810	0.706	2.641 s
DWT[4]	0.671	0.683	8.61	1.761	0.704	31.703 s
GLP[5]	0.798	0.810	5.57	1.416	0.819	2.157 s
HPM[6]	0.810	0.808	4.80	1.315	0.830	3.25 s
Proposed	**0.840**	**0.835**	**3.83**	**1.174**	**0.853**	**0.5 s**

4. REFERENCES

[1] W. Carper, T. Lillesand, and R. Kiefer, "The use of intensity-hue-saturation transformations for merging SPOT panchromatic and multispectral image data*," Photogramm. Eng. Remote Sens*, vol. 56, no. 4, pp. 459-467, Apr. 1990.

[2] T.-M. Tu, P.S. Huang, C.-L. Hung, and C.-P. Chang, "A Fast Intensity-Hue-Saturation Fusion Technique With Spectral Adjustment for IKONOS Imagery," *IEEE Geosci. Remote Sens. Lett.*, vol. 1, no. 4, pp. 309-312, Oct. 2004.

[3] P.S. Chavez, J. Stuart, C. Sides, and J.A. Anderson, "Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic," *Photogramm. Eng. Remote Sens*, vol. 57, no. 3, pp. 259-303, Mar. 1991.

[4] J. Nunes, X. Otazu, O. Fors, A. Prades, V. Pala, and R. Arbiol, "Multiresolution-based image fusion with additive wavelet decomposition*," IEEE Trans. Geosci. Remote Sens.*, vol. 37, no. 3, pp. 1204-1211, May. 1999.

[5] B. Aiazzi, L. Alparone, S. Baronti, I. Pippi, and M. Selva, "Generalized Laplacian pyramid-based fusion of MS+P image data with spectral distortion minimization*," ISPRS Int. Archives Photogramm. Remote Sens.*, vol. 34, no. 3B-W3, pp. 3-6, Sep. 2002.

[6] R. A. Schowengerdt, Remote Sensing: Models and Methods for Image Processing, 2nd ed. Orlando, FL: Academic, 1997.

[7] Z. Wang and A.C. Bovik, "A universal image quality index*," IEEE Signal Process. Lett.*, vol. 9, no. 3, pp. 81-84, Mar. 2002.

[8] L. Alparone, S. Baronti, A. Garzelli, and F. Nencini, "A global quality measurement of pan-sharpened multispectral imagery," *IEEE Geosci. Remote Sens. Lett.*, vol. 1, no. 4, pp. 313-317, Oct. 2004.

[9] L. Wald, T. Ranchin, and M. Mangolini, "Fusion of satellite images of different spatial resolutions: Assessing the quality of resulting images*," Photogramm. Eng. Remote Sens*, vol. 63, no. 6, pp. 691-699, Jun. 1997.