Guided Filter and IHS-Based Pan-Sharpening

Amina Jameel, Muhammad Mohsin Riaz, and Abdul Ghafoor

***Abstract*— A guided filter and intensity–hue–saturation-based pan-sharpening scheme is proposed. The scheme combines the high-resolution unispectral and low-resolution multispectral images considering the intensity levels and the spatial information. Guided filtering is used to further refine the weight maps for each pixel. The simulation results show that the suggested scheme mostly yields superior results compared with the existing schemes.**

***Index Terms*— Pan-sharpening, image fusion, guided filter.**

I. Introduction

SATELLITE sensors provide high resolution panchromatic (HRP) for land covers and low resolution multi-spectral (LRM) images [1] for shapes and structures [2]. Obtaining image with both high spatial and spectral resolutions is necessary for a range of remote sensing applications. Pan-sharpening aims to create a high resolution multispectral (HRM) image by fusing the information of LRM and HRP images [2].

Pan-sharpening methods are grouped into linear combination approximation (LCA) methods (intensity-hue-saturation (IHS), Brovey transform and principal component analysis (PCA) [2], [3]) and spatial filter approximation (SFA) methods (high-pass filtering, high-pass modulation, and the multi-resolution analysis [4], [5]). The LCA methods have lower computational cost and are less sensitive to mis-registration, however both (LCA and SFA) produce spectral distortion [2].

Beside other methods, IHS based methods are widely used for pan-sharpening due to fast implementation and high spatial resolution [3]. To overcome the low spectral resolution problem, various modifications have been proposed [2], [6]–[9]. A fast spectrally adjusted extended IHS (EIHS) pan-sharpening method for Ikonos imagery [6] is not effective for other type of satellite images [2]. Vegetation [7] and modified vegetation indexes [8] were proposed to overcome the unnatural color response in order to enhance and extract vegetation. Adaptive IHS (AIHS) technique [9] adaptively adjust the coefficients of the multi-spectral bands. However, the weights induced by the edges of the HRP image sometimes become too large, thus result in color changes of the vegetation areas [2]. Recently, an improved AIHS (IAIHS) method [2] was proposed to overcome these issues. However, the HRM image appears too have to many edges.

To overcome the spectral distortion, an improved guided filter (GF) and IHS (GFIHS) technique is proposed for pansharpening. The scheme combines the high-resolution uni-spectral and low-resolution multispectral images taking into account the intensity levels and spatial information. GF is used to further refine the weight maps for each pixel. Quantitative analysis on Ikonos and Quickbird datasets show that the proposed scheme is a significant improvement as compared to the state of art pan-sharpening schemes.

II. IAIHS Fusion [2]

Let P and M be the HRP and LRM images respectively, the generalized IHS fusion scheme is [2],

$$F_k = M_k + \Gamma_k \odot \big(P - I\big) \tag{1}$$

where $\odot$ is point-wise operator, Γ_k is the weight matrix, F_k is the fused image and $k = 1, 2, \ldots, K$ represent the bands of LRM image. The intensity image I is,

$$I = \sum_{k=1}^{K} \alpha_k M_k \tag{2}$$

The coefficients α_k are obtained by solving the minimization problem, i.e.,

$$\min \|P - \sum_{k=1}^{K} \alpha_k M_k\|^2 \quad \text{such that} \quad \alpha_1, \ldots, \alpha_K \geq 0 \tag{3}$$

The weight matrix Γ_k^{IAIHS} of IAIHS scheme is obtained by using both the information of HRP and LRM images, i.e.,

$$\Gamma_k^{\text{IAIHS}} = \frac{K\Big(\beta\Gamma_P + (1-\beta)\Gamma_{M_k}\Big)M_k}{\sum_{k_1=1}^{K} M_{k_1}} \tag{4}$$

where $\beta \in [0, 1]$ is a contribution control parameter. Γ_P and Γ_{M_k} are the HRP and LRM induced weights respectively, i.e.,

$$\Gamma_P = \exp\left(\frac{-\lambda}{|\nabla P|^4 + \epsilon}\right) \quad \text{and} \quad \Gamma_{M_k} = \exp\left(\frac{-\lambda}{|\nabla M_k|^4 + \epsilon}\right) \tag{5}$$

where λ and ϵ are the tuning parameters and $|\nabla P|$ and $|\nabla M_k|$ are the gradient of the HRP and LRM images respectively. Note that $\Gamma_k^{\text{AIHS}} = \Gamma_P$ and $\Gamma_k^{\text{EIHS}} = \mathbf{1}$ for AIHS [9] and extended IHS [6] schemes respectively.

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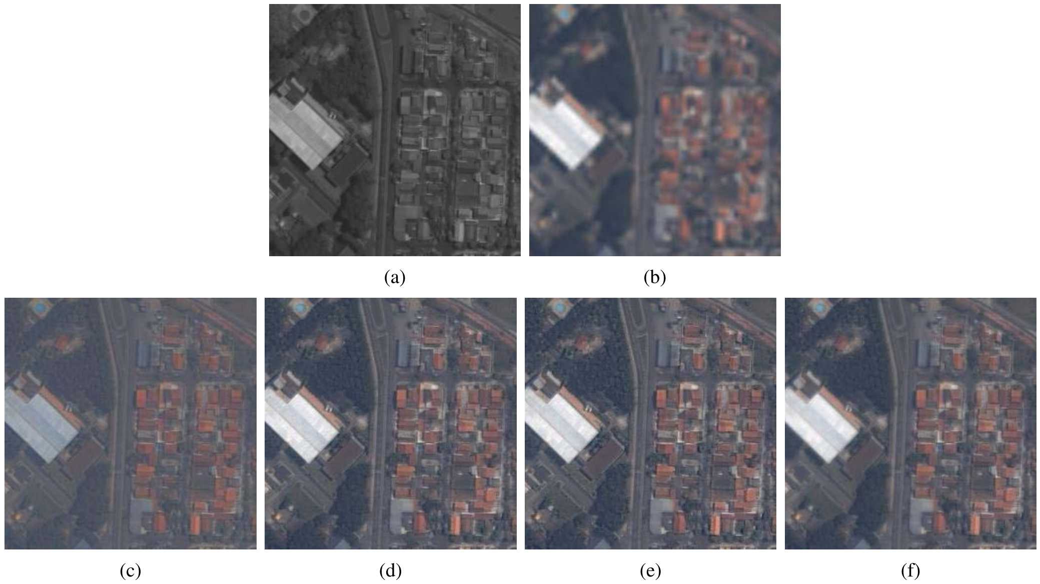

Fig. 1. Example 1: Visual comparison of different fusion schemes (imagery courtesy of space imaging LLC). (a) HRP image. (b) Interpolated LRM image. (c) PCA [10] fusion. (d) AIHS [9] fusion. (e) IAIHS [2] fusion. (f) Proposed GFIHS fusion.

III. PROPOSED GFIHS FUSION

To minimize the spectral distortion problem (in IAIHS method [2]), GF (an edge-preserving smoothing filter) based weight computation technique is proposed. Instead of using both the LRM and HRP images for weighing matrix Γ, a better approach i.e. LRM image guided by the edges of the HRP image is presented.

The HRP image is passed through a laplacian filter L of size 3×3 to obtain the high-pass image H.

$$H = P * L \tag{6}$$

The initial weights ξ_k are constructed as,

$$\xi_k = \begin{cases} 1 & \text{if } M_k = \max\left(M_1, M_2, \ldots, M_K\right) \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

ξ_k and H are then passed through a GF $G_{\nu,\omega}$ [11] to obtain the refined weights Γ_k^{GF} for spatial detail injection i.e.,

$$\Gamma_k^{\mathrm{GF}} = G_{\nu,\omega}(\xi_k, H) \tag{8}$$

where ν, ω represent the filter size and blur degree of GF respectively.

The use of a different weight matrix for each multipectral band in the injection step increases the spectral quality but at the cost of huge decrease in spatial quality of the fused image. A separate Γ_k for each band results in over-injection of high frequency components in the fused image. Therefore, in order to simultaneously improve both the spatial and the spectral quality, one weight matrix is selected for all the bands based on the spatial information of the LRM image. The average gray level value μ_k of each band of the LRM image is calculated. The weight matrix Γ_k corresponding to the multispectral band having the highest mean value is then used for spatial detail injection step.

$$\Gamma^{\mathrm{GFIHS}} = \Gamma_k^{\mathrm{GF}} \quad \text{such that} \quad \mu_k \equiv \arg\max_k \left(\mu_k\right) \tag{9}$$

where Γ^{GFIHS} is the weight matrix used for all the bands of the LRM image. The use of Γ^{GFIHS} in the spatial injection step not only increases the spectral quality but also improves the spatial quality of the fused image.

IV. RESULTS AND ANALYSIS

For analysis and comparison of proposed and existing schemes, four-band (red, blue, green, and near infrared) multispectral QuickBird, and Ikonos data is used. The resolutions for Ikonos imagery are $1m$ and $4m$ for HRP (size 256×256) and LRM (size 64×64) images respectively. The resolutions for Quickbird imagery are $0.65m$ and $2.62m$ for HRP (size 256×256) and LRM (size 64×64) images respectively. LRM bands were interpolated using bicubic interpolation and the parameter values are set as $\lambda = 10^{-9}$ and $\epsilon = 10^{-10}$. The proposed and state of art the existing schemes (including PCA [10], AIHS [9], and IAIHS [2]) are simulated using Matlab software on Pentium Dual Core 64-bit CPU having 3GB RAM.

Quantitative analysis is performed using spectral angle mapper (SAM), relative dimensionless global error in synthesis (ERGAS), spectral information divergence (SID), universal image quality index (Q), relative average spectral error (RASE), correlation coefficient (CC), root mean squared error (RMSE) and spatial coefficient (SC) [9]. Lower values of CC, ERGAS, RASE, RMSE, SAM, SID, computational time and higher values of Q and SC indicates a better pansharpened image.

The spectral distortion of the PCA scheme is clearly visible (Fig. 1 (c) and Fig. 2 (c)) as colors do not match the original LRM image. The IAIHS fused image suffers from over-injection of the high-frequency information from the HRP image. The spectral distortion caused by IAIHS method is most visible in the areas covered by vegetation (Fig. 1 (e)) and forest (Fig 2 (e)). The AIHS method (Fig. 1 (d) and (Fig 2 (d)) and the proposed method (Fig. 1 (f) and (Fig 2 (f)) produce images whose colors better

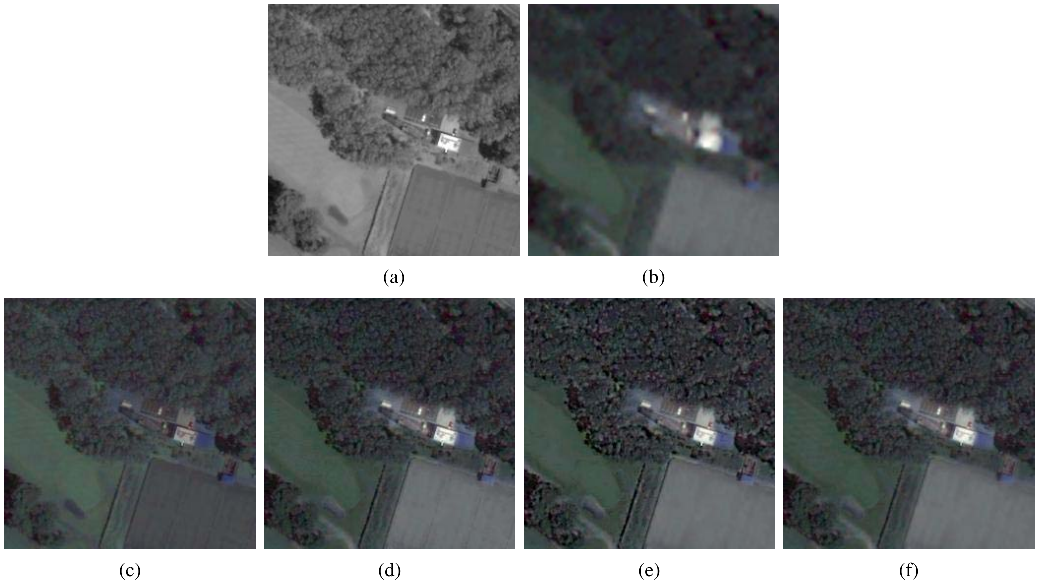

Fig. 2. Example 2: Visual comparison of different fusion schemes (imagery courtesy of space imaging DigitalGlobe). (a) HRP image. (b) Interpolated LRM image. (c) PCA [10] fusion. (d) AIHS [9] fusion. (e) IAIHS [2] fusion. (f) Proposed GFIHS fusion.

TABLE I

QUANTITATIVE COMPARISON OF PROPOSED AND EXISTING SCHEMES

Examples	Techniques	CC (0)	ERGAS (0)	Q (1)	RASE (0)	RMSE (0)	SAM (0)	SID (0)	SC (1)	Time (sec)
Example 1	PCA [10]	0.2122	4.105	0.9586	16.21	12.710	1.388	0.0156	0.9213	0.085
	AIHS [9]	0.0031	2.326	0.9907	9.267	7.262	0.4320	0.0023	**0.9721**	0.860
	IAIHS [2]	0.0073	2.576	0.9889	10.27	8.054	0.5328	0.0092	0.9653	0.896
	Proposed GFIHS	**0.0021**	**1.785**	**0.9943**	**7.118**	**5.578**	**0.3561**	**0.0016**	0.9680	0.982
Example 2	PCA [10]	0.3240	6.704	0.7505	21.86	17.69	5.331	0.0118	0.9406	0.053
	AIHS [9]	0.0131	3.137	0.9916	11.17	9.051	**1.748**	0.0047	0.9337	0.747
	IAIHS [2]	0.0771	4.807	0.9774	17.21	13.93	2.925	0.0191	0.8789	0.838
	Proposed GFIHS	**0.0041**	**2.976**	**0.9921**	**10.58**	**8.573**	1.792	**0.0046**	**0.9643**	0.906

match the original image. However, quantitative analysis indicate that the GFIHS fused image is of higher spectral quality compared to the AIHS fused image.

It can be seen in Table 1 that the proposed scheme yields the best pan-sharpening performance in terms of most of the image quality indexes. Note that the slight increase (as compared to AIHS [9] and IAIHS [2]) in the computational time is due to the additional weight refinement step using guided filter.

V. CONCLUSIONS

An improved GFIHS pan-sharpening scheme to preserve both spectral and geometric information is presented. The scheme combines the HRP and LRM images taking into account the intensity levels and spatial information. IHS is used for image decomposition while GF is used for weight refinement. Simulation results over different satellite imageries show the significance of proposed scheme.

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