HYBRID COMPONENT SUBSTITUTION AND WAVELET BASED IMAGE FUSION

Syed Sohaib Ali, Muhammad Mohsin Riaz, Abdul Ghafoor

Department of Electrical Engineering, College of Signals
National University of Sciences and Technology (NUST)
Islamabad, Pakistan

ABSTRACT

A two step hybrid image fusion scheme is proposed for panchromatic and multi-spectral satellite sensors. First, we estimate an intermediate high/low resolution multi-spectral image using component substitution, which is followed by additive wavelet based high frequency injection into low resolution multi-spectral bands. Spectral dissimilarities between panchromatic and multi-spectral bands are taken into account while devising partial replacement strategy for component substitution. Quantitative analysis performed on Ikonos data set demonstrates that the proposed scheme outperforms state of the art multi-resolution image fusion schemes.

***Index Terms*—** Image Fusion, Panchromatic Sharpening

1. INTRODUCTION

The panchromatic sharpening of satellite images is performed by fusing monochrome High resolution Panchromatic (HRP) image with Low Resolution Multi-spectral (LRM) images. The effective fusion schemes employed to produce High Resolution Multi-spectral (HRM) images include Component Substitution (CS) based methods and multi-resolution based schemes. The CS-based schemes like Intensity-Hue-Saturation (IHS) and its variants [2] - [6], brovey transform and principal component analysis are computationally least expensive and produce superior visual HRM images but result in spectral degradation [7]. Compared with standard CS-based methods, the wavelet-based multi-resolution fusion schemes produce superior radiometric quality [8, 6]. Moreover, these methods are better suited as a trade-off between the radiometric and geometric information [9].

Amongst several wavelet-based fusion schemes [8], [10] - [12], the algorithms based on decimated wavelet transform like “Mallat algorithm” require sub-sampling, resulting in linear discontinuity of features such as edges and the emergence of artifacts in structures which are neither horizontal nor vertical in direction. The undecimated schemes like $\grave{a}$ trous algorithm are shift invariant and thus better suited for image fusion [10].

The $\grave{a}$ trous based fusion is executed either by replacing frequency components of LRM image by corresponding high frequencies of HRP image (known as Substitute-Wavelet (SW) method) or by injecting high frequency components of HRP image into LRM image (known as the Additive-Wavelet (AW) method) [11]. However, the addition of same high frequency in every LRM band causes AW method to generate redundant high frequency [8]. On the contrary, SW method totally eliminates wavelet planes of LRM image. The substitution process in SW-based methods can cause artifacts in fused image which may result in both geometric and spectral distortions [1].

To avoid such artifacts, a hybrid image fusion scheme is proposed which uses CS-based fusion to reduce redundant frequencies resulting from AW-based fusion. The CS-based intermediate fusion also utilizes spectral similarities between low resolution HRP and LRM images. Alongwith HRP image, the spatially degraded version of the intermediate fused image is used to determine the amount of spatial information that is incorporated in final fused image. The proposed scheme provides superior visual quality preserving both spatial and spectral content.

2. AW-BASED IMAGE FUSION

Let HRP image $I_{\hat{\mathrm{HRP}}}$ be represented as sum of low $I_{\hat{\mathrm{HRP}},\,\mathrm{L}}$ and high frequency components $I_{\hat{\mathrm{HRP}},\,\mathrm{H}}$ i.e,

$$I_{\hat{\mathrm{HRP}}}(m,n) = I_{\hat{\mathrm{HRP}},\,\mathrm{L}}(m,n) + I_{\hat{\mathrm{HRP}},\,\mathrm{H}}(m,n) \qquad (1)$$

where $m \in \{1,2,3,\ldots,M\}$ and $n \in \{1,2,3,\ldots,N\}$ represent number of rows and columns respectively. Similarly, let LRM image $I_{\hat{\mathrm{LRM}}}$ be represented as the sum of low $I_{\hat{\mathrm{LRM}},\,\mathrm{L}}$ and high frequency components $I_{\hat{\mathrm{LRM}},\,\mathrm{H}}$ i.e.,

$$I_{\hat{\mathrm{LRM}}}(\hat{m},\hat{n},\beta) = I_{\hat{\mathrm{LRM}},\,\mathrm{L}}(\hat{m},\hat{n},\beta) + I_{\hat{\mathrm{LRM}},\,\mathrm{H}}(\hat{m},\hat{n},\beta) \qquad (2)$$

where $\hat{m} \in \{1,2,3,.....\hat{M}\}$ represents number of rows, $\hat{n} \in \{1,2,3,.....\hat{N}\}$ represents number of columns and $\beta \in \{\mathrm{R,G,B,NIR}\}$ are red, green, blue and infrared band indices of $I_{\hat{\mathrm{LRM}}}$ image. Each band of $I_{\hat{\mathrm{LRM}}}$ image is scaled to match the dimensions of $I_{\hat{\mathrm{HRP}}}$ image to obtain I_{LRM}. The histogram of the $I_{\hat{\mathrm{HRP}}}$ is matched with intensity component of I_{LRM} to obtain I_{HRP} image.

The AW-based methods insert the same amount of high frequency information of HRP image into every LRM band which causes radiometric distortion. On the other hand, AW-Luminance-Proportional (AWLP) method [19] injects high frequency into each LRM band proportional to its intensity levels (thus preserving the relative radiometric information between LRM bands to an extent), i.e.,

$$I_{\text{HRM, AWLP}}(m,n,\beta)= I_{\text{LRM}}(m,n,\beta)+\frac{I_{\text{LRM}}(m,n,\beta)}{\frac{1}{\beta}\sum_{\beta} I_{\text{LRM}}(m,n,\beta)}\sum_{j=1}^{J} W_{\text{HRP, }j}(m,n) \quad (3)$$

where $W_{\text{HRP, }j}$ represents j^{th} wavelet plane of I_{HRP}. It is assumed that low frequencies in the fused image are provided by I_{LRM} while high frquencies are estimated by J wavelet planes. Although AWLP method preserves relative radiometric signatures amongst fused bands but still, this method can cause injection of redundant frequency information. Recently, Improved Additive Wavelet Proportional (IAWP) method [8] is proposed to overcome this limitation which considers a low pass version of HRP image during injection process. Let I_{LRP} represent a Low Resolution Panchromatic (LRP) image, which is a spatially degraded version of HRP band obtained by filtering high frequencies [8, 13]. IAWP method is given by,

$$I_{\text{HRM, IAWP}}(m,n,\beta) = I_{\text{LRM}}(m,n,\beta) + \frac{I_{\text{LRM}}(m,n,\beta)}{\frac{1}{\beta}\sum_{\beta} I_{\text{LRM}}(m,n,\beta)}\sum_{j=1}^{J} W_{\text{HRP-LRP, }j}(m,n) \quad (4)$$

where $W_{\text{HRP-LRP}}$ represents a particular wavelet plane of the difference image ($I_{\text{HRP}} - I_{\text{LRP}}$). Hence only that amount of high frequencies are inserted which are not presented in I_{LRP}.

3. PROPOSED SCHEME

As stated earlier, CS-based fusion schemes often produce spectral degradation while AW-based methods can cause spatial distortion due to redundant high frequencies. The motivation of this work comes from the fact that we can merge these schemes so that one can cover the limitations of another. In the following, we present an effective hybrid fusion scheme which injects necessary geometric information while preserving the radiometric information.

3.1. Proposed CS-Based Intermediate Fusion

CS-based fusion schemes usually involve adjustment of corresponding parameters in order to make the fused image as similar as possible to the LRM image [3, 4]. The Fast IHS method with Spectral Adjustment (FIHS-SA) [2] calculates such parameters through experimental coefficients for IKONOS imagery. In General IHS - Genetic Algorithm (GIHS-GA) [4], every coefficient is optimized my means of a genetic algorithm. The Fast IHS method with a Tradeoff Parameter (FIHS-TP) [3] uses a tradeoff through experimental procedures while Gram-Schmidt (GS) [5] spectral sharpening algorithms depend upon mathematical sensor model and data analysis. Most of these algorithms do not produce the desired results as the spatial characteristics of a particular scene are not taken into account. Therefore, CS-based fusion schemes must incorporate global and local similarities between panchromatic and multi-spectral images [6].

An intermediate high resolution multi-spectral image, I_{HRMI} is estimated using LRP and LRM images through partial replacement [1]. I_{LRP} is obtained by filtering I_{HRP} using Modulation Transfer Function (MTF) shaped gaussian low pass filter [8, 13]. The MTF gain of panchromatic band as measured using the Nyquist frequency along a track system is 0.165 for Ikonos imagery [8]. Correlation coefficient is used as a similarity metric. These similarities must be considered because the spectral relationship between LRP and LRM images vary with each band. We propose IHS-based fusion as follows.

$$I_{\text{HRMI}}(m,n,\beta) = 2\Big[R_\beta \cdot I_{\text{H}\hat{\text{R}}\text{P}}(m,n)\Big] + 2\Big[(1-R_\beta)\cdot I_{\text{LRM}}(m,n,\beta)\Big] - \frac{1}{\beta}\sum_{\beta} I_{\text{LRM}}(m,n,\beta) \quad (5)$$

where R_β denotes the correlation coefficient between LRP and β-band of I_{LRM}. R_β characterizes the spectral similarity between panchromatic and a specific multi-spectral band, which determines the contribution of HRP and a specific LRM band in I_{HRMI} image. For higher values of R_β, the contribution of $I_{\text{H}\hat{\text{R}}\text{P}}$ is higher and vice versa. In eq. 5, the intensity image is obtained by averaging I_{LRM} across all multi-spectral bands.

3.2. Proposed AW-Based Fusion

The intermediate fused image, I_{HRMI}, is used to reduce injection of redundant frequencies in AW-based fusion as follows,

$$I_{\text{HRM}}(m,n,\beta) = I_{\text{LRM}}(m,n,\beta) + \frac{I_{\text{LRM}}(m,n,\beta)}{\frac{1}{\beta}\sum_{\beta} I_{\text{LRM}}(m,n,\beta)}\sum_{j=1}^{J} W_{\text{HRP - LRMI, }j}(m,n,\beta) \quad (6)$$

where I_{LRMI} represents an intermediate low resolution multi-spectral image obtained by filtering high frequencies of I_{HRMI} using MTF shaped gaussian low pass filter for each band [13, 18]. For Ikonos imagery, the Red, Green, Blue and NIR bands are filtered using MTF gains of 0.29, 0.28, 0.27, 0.28 respectively [17]. The proposed scheme adds high frequencies by decomposing wavelet planes of the difference image

Table 1: Comparison of spatial and spectral quality indices for Ikonos Imagery

Techniques	Zhou's Protocol		Khan's Protocol		Alparone's Protocol		
	D_λ	D_S	D_λ	D_S	D_λ	D_S	QNR
FIHS-SA	30.805	0.004	0.153	0.428	0.106	0.124	0.783
GS	26.710	0.010	0.092	0.320	0.082	0.101	0.825
AWLP	21.493	0.036	0.056	0.381	0.087	0.092	0.829
IAWP	19.158	0.107	0.041	0.252	0.058	0.087	0.860
Proposed Scheme	16.422	0.286	0.037	0.206	0.040	0.062	0.901
Interpolated Image	12.165	0.629	0.018	0.479	0.003	0.253	0.744

$I_{\text{HRP - LRMI}}$. Unlike IAWP method which uses a single band of HRP image and its degraded version, the proposed scheme uses HRP image alongwith all bands of intermediate low resolution multi-spectral image to determine content of high frequency information. For each band, the wavelet planes of HRP band are added while those of corresponding band in I_{LRMI} are discarded.

4. EXPERIMENTS AND RESULTS

The Ikonos imagery with panchromatic band having resolution of $1m$, and red, green, blue, NIR bands having resolution of 4m was used for evaluation purposes. Simulation includes LRM images having dimensions of 512×512 pixels per band and HRP band having dimension of 2048×2048 pixels. LRM Images are shown as a RGB combination re-sampled at $1m$ using bi-cubic interpolation. Although not shown, the NIR band was processed and numerically evaluated in the same way. Amongst CS-based methods, we compare our results with FIHS-SA and GS, as GS produces the best results while FIHS-SA is the fastest [17]. Amongst wavelet based schemes, AWLP which was the joint winner in 2006 GRS-S Data-Fusion Contest [15] and its improved version IAWP is chosen for comparison.

4.1. Visual Analysis

The visual performance of existing and proposed image fusion schemes, evaluated over an RGB composition of 300×300 pixels of Ikonos images is presented in Fig. 1. It is visible that CS-based schemes suffer from spectral distortion although GS-fused image is less sharp than FIHS-SA fused image. AW-based schemes preserves spectral content better, however IAWP seems less sharp than AWLP. The intermediate fused image also suffers from spectral distortion. Compared to these schemes, the proposed fused image preserves both geometric and radiometric details.

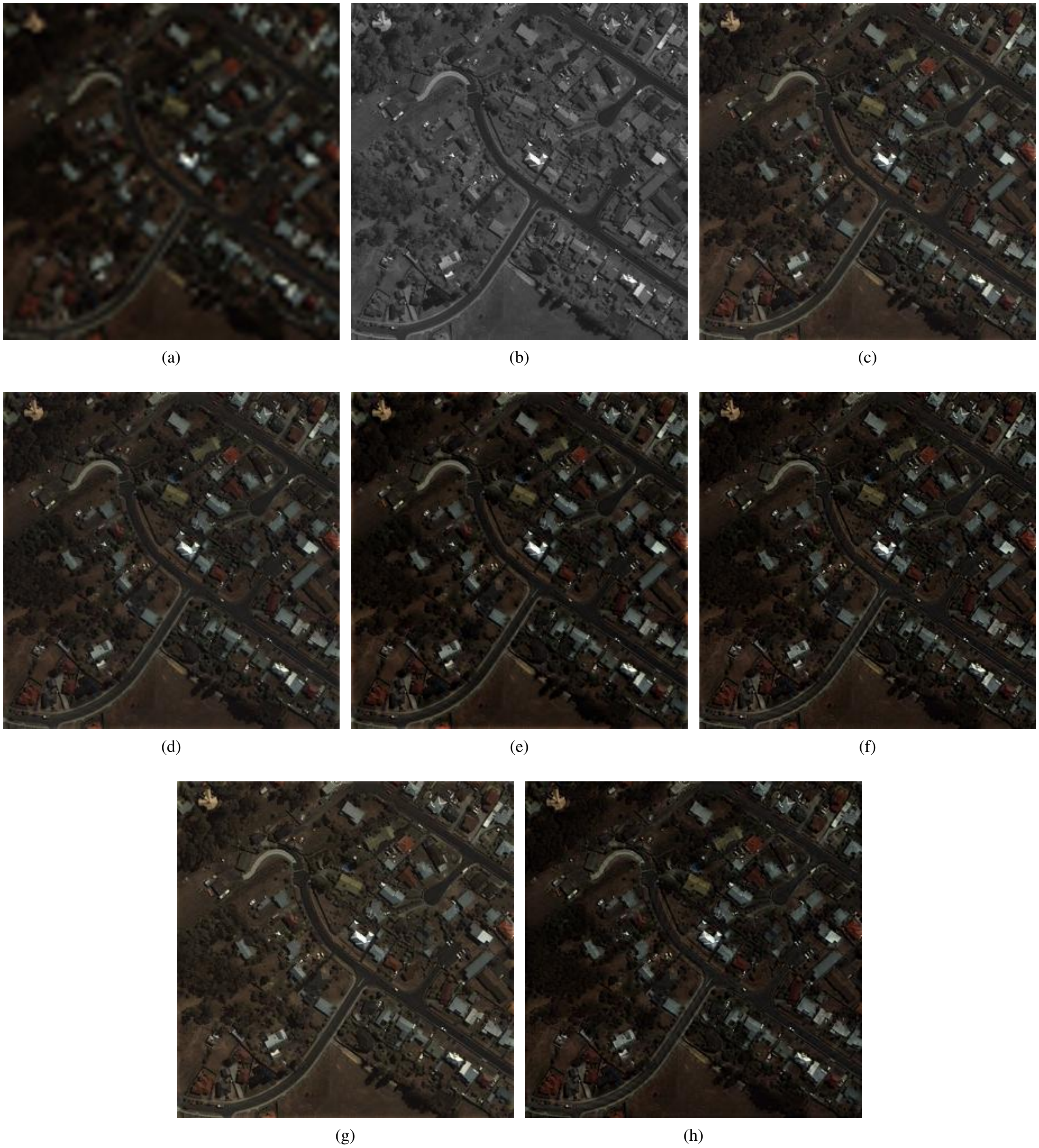
4.2. Quantitative Analysis

Literature describes several statistical evaluation measures like Q4, Spectral Angle Mapper (SAM), and relative dimensionless global error in synthesis (ERGAS). SAM mostly measures radiometric distortion, whereas ERGAS and Q4 fail to quantify relative sensitivity between radiometric and geometric distortion separately. All of these require a reference multi-spectral image at the same spatial resolution as that of the fused image which is not available for Ikonos imagery. The alternative quantitative assessment by spatial degradation of original data set is also not suitable for high resolution satellite imagery [14, 16].

Fusion quality can also be assessed without a reference high quality multi-spectral image. These include measures proposed in [17, 21, 16]. We have used the same metrics to assess fusion quality. However, Zhou's method [21] provides inconsistent results. Although Zhou's protocol computes spectral and spatial qualities indices separately, but the computation of spatial quality assessment is incorrect, as illustrated in [20]. When compared with Q4, ERGAS, and SAM, Zhou's spatial quality index can follow behavior contradictory to that of indices computed with a reference [16]. Table 1 enlists the spatial and spectral distortion indices for Ikonos imagery denoted by D_S and D_λ respectively. *Alparone et al.* [16] combine D_S and D_λ to yield a single fusion quality index, Quality with no reference (QNR). The low values of D_S and D_λ indicate low spatial and spectral distortion respectively, which results in high value of QNR and vice versa. Due to lack of reference, interpolated LRM image is chosen as spectral reference (reference for colors).

5. CONCLUSION

The critical issue of preserving both radiometric and geometric information during fusion process is addressed. An intermediate fused image is estimated to reduce redundant high frequency information in traditional additive wavelet fusion schemes. We propose $\grave{a}$ torus based fusion scheme which preserves LRM bands and injects high frequencies using spatial characteristics of multi-spectral and panchromatic bands. The proposed method evaluated over Ikonos imagery provided superior fusion quality than recently proposed methods.



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 1: A sub section of (a) $4m$ LRM image interpolated at $1m$, (b) HRP image at $1m$, (c) FIHS-SA fused image (d) GS fused image (e) AWLP fused image (f) IAWP fused image, (g) Intermediate Fused Image, (h) Proposed fused image. (Imagery courtesy of Space Imaging, LLC).

6. REFERENCES

[1] C. Thomas, T. Ranchin, L. Wald and J. Chanussot, “Synthesis of multispectral images to high spatial resolution: a critical review of fusion methods based on remote sensing physics,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 46, no. 5, pp. 1301-1312, 2008.

[2] T. M. Tu, P. S. Huang, C. L. Hung, and C. P. Chang, ”A fast intensity huesaturation fusion technique with spectral adjustment for IKONOS imagery,” *IEEE Geoscience and Remote Sensing letters*, vol. 1, no. 4, pp. 309-312, Oct. 2004.

[3] M. Choi, ”A new intensity-hue-saturation fusion approach to image fusion with a tradeoff parameter,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 44, no. 6, pp. 1672-1683, Jun. 2006.

[4] A. Garzelli and F. Nencini, ”Fusion of panchromatic and multispectral images by genetic algorithms,” *IEEE International Geoscience and Remote Sensing Symposium*, 2006, pp. 3810-3813.

[5] C. A. Laben and B. V. Brower,”Process for enhancing the spatial resolution of multispectral imagery using pansharpening,” *U.S. Patent 6 011 875*, Jan. 4, 2000.

[6] J. Choi, K. Yu, and Y. Kim, ”A New Adaptive Component-Substitution-Based Satellite Image Fusion by Using Partial Replacement,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, no. 1, pp. 295-308, Jan. 2011.

[7] Z. Wang, D. Ziou, C. Armenakis, D. Li and Q. Li, “A comparative analysis of image fusion methods,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 43, no. 6, pp. 1391-1402, 2005.

[8] Y. Kim, C. Lee, D. Dan, Y. Kim and Y. Kim, “Improved additive-wavelet image fusion,” *IEEE Geoscience and Remote Sensing Letters*, vol. 8, no. 2, pp. 263-267, 2011.

[9] M. Saavedra and C. Gonzalo, “Spectral or spatial quality for fused satellite imagery? A trade-off solution using the wavelet à trous algorithms,” *International Journal of Remote Sensing*, vol. 22, no. 7, pp. 1453-1464, 2006.

[10] M. G. Audicana, X. Otazu, O. Fors and A. Seco, “Comparison between the Mallat’s and the à trous discrete wavelet transform based algorithms for the fusion of multispectral and panchromatic images,” *International Journal of Remote Sensing*, vol. 26, no. 3, pp. 597-616, 2005.

[11] X. Nunez, X. Otazu, A. Prades, V. Pala and R. Arbiol, “Multiresolution-based image fusion with additive wavelet decomposition,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 37, no. 3, pp. 1204-1211, 1999.

[12] S. Ali, M. Riaz, and A. Ghafoor, “Fuzzy logic and additive wavelet based image fusion,” *IEEE International Symposium on Circuits and Systems*, in press, 2013.

[13] B. Aiazzi, L. Alparone, S. Baronti, A. Garzelli and S. Selva , “MTF tailored multiscale fusion of high-resolution MS and Pan imagery,” *Photogrammetric Engineering & Remote Sensing*, vol. 72, no. 5, pp. 591-596, 2006.

[14] L. Alparone, S.Baronti, A. Garzelli, and F. Nencini, “A global quality measurement of pan-sharpened multispectral imagery,” *IEEE Geoscience and Remote Sensing letters*, vol. 1, no. 4, pp. 313-317, 2004.

[15] L. Alparone, L. Wald, J. Chanussot, C. Thomas, P. Gamba and L. M. Bruce, “Comparison of pansharpening algorithms: Outcome of the 2006 GRS-S data-fusion contest,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 10, pp. 3012-3021, 2007.

[16] L. Alparone, B. Aiazzi, S. Baronti, A. Garzelli, F. Nencini and M. Selva, “Mutltispectral and panchromatic data fusion assessment without reference,” *Photogrammetric Engineering & Remote Sensing*, vol. 74, no. 2, pp. 193-200, 2004.

[17] M. M. Khan, L. Alparone and J. Chanussot, “Pansharpening quality assessment using the modulation transfer functions of instruments,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, no. 11, pp. 3880-3891, 2009.

[18] J. Lee and C. Lee, “Fast and efficient panchromatic sharpening,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 48, no. 1, pp. 155-163, 2010.

[19] X. Otazu, M. G. Audicana, O. Fors and J. Nunez, “Introduction of sensor spectral response into image fusion method. Application to wavelet-based methods,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 43, no. 10, pp. 2376-2385, 2005.

[20] C. Thomas and L. Wald, “Comparing distances for quality assessment of fused images,” *26th EARSeL Symposium on New Developments and Challenges in Remote Sensing*, Warsaw, Poland, pp. 101-111, 2006.

[21] J. Zhou, D. L. Civco and J. A. Silander, “A wavelet transform method to merge Landsat TM and SPOT panchromatic data,” *International Journal of Remote Sensing*, vol. 19, no. 4, pp. 743-757, 1998.