Pan-sharpening WorldView-2: IHS, Brovey and Zhang methods in comparison

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***Abstract*–Pan-sharpening methods permitto synthetize new imagesstarting from panchromatic and multispectral data. The first type of images hasa higher spatial resolution but a lower radiometric resolution than the second. Fused images have the radiometric information of the multispectral data and the pixel dimensions of the panchromatic data. In this paper, three pan-sharpening methods to improve geometric characteristics of the multispectral images are considered:IHS (Intensity, Hue, Saturation), Brovey and Zhang. WorldView-2 Very High Resolution satellite imagery isconsidered to test these methods.Correlation Coefficient, ERGAS (Erreur Relative Globale Adimensionalle de Synthèse), and UIQI(Universal Image Quality Index)are taken into account to evaluate the quality of the obtained fused images.**

Keywords - WorldView-2, IHS-Pan-sharpening, Brovey, Zhang, Correlation Coefficient, ERGAS, UIQI

I. INTRODUCTION

In remote sensing, Pan-sharpening methods permit to integrate the geometric detail of panchromatic (PAN) image with the radiometric detail of multispectral (MS)ones at a lower spatial resolution [1],[2],[3]. In the last years, several applications about uses of pan-sharpening techniques on satellite images were conducted. In 2010, Rahmani et al. [4] proposed image-adaptive coefficients to improve the IHS (Intensity, Hue, Saturation) method and to obtain more accurate spectral resolution.In 2012, Aguilar et al. [5] applied pan-sharpening techniques to GeoEye-1 and WorldView-2 images used for an object-based classification in urban environments; they used this application to evaluate the accuracy of the classification by pan-sharpened orthoimages. Maglione et al. [6], in 2015, used WorldView-2 imagery to reconstruct the recent evolution of the Domitian Coastline; Zhang pan-sharpening method to improve spatial resolution of the multispectral images was used. Meneghini and Parente [7]used IHS pan-sharpening applied to GeoEye-1 images to test a new index for shadow detection.Finally, Belfiore and Parente [8] tested the use of WorldView-2 images to produce High Resolution Coloured Ortho-Photos by orthorectification and pan-sharpening; they considered Zhang method to improve spatial resolution of the multispectral images.

The performance evaluation of pan-sharpening techniques is particularly investigated [9],[10],[11]. A lot of researchershave used several indexes, utilized in the image processing field, to test results of fusion methods. For example, in 2013, Mandhare et al. [12] used entropy, standard deviation, RMSE and PSNR to compare fused and original images acquired by Landsat 7 ETM+; they considered several pan-sharpening techniques as Averaging, Multiplicative, Brovey, Wavelet. In 2015, Palubinskas [13]proposed a new index to define the quality ranking of pan-sharpening methods; it is known as Joint Quality Measure (JQM) and it is a composite measure that has two terms: the former is measured between a low passfiltered pan-sharpened image and original multispectral image at a reduced/low resolution scale; the latter is measured between the intensity calculated from a spectrally weighted pan-sharpened multispectral image and an original panchromatic image in a high resolution scale.

The aim of this paper is to evaluate three different pan-sharpening techniques applied tovery high-spatial resolution remotely sensed images by using different indexes to test the quality of the fused image.

The applications were carried out on WorldView-2 images. The pan-sharpening techniques used were: the IHS, the Brovey and the Zhang algorithms. The quality of the fused images were evaluated bythe following indexes: Correlation Coefficient, ERGAS(Erreur Relative Globale Adimensionalle de Synthèse)and UIQI (Universal Image Quality Index).

II. DATA AND METHODS

A. WorldView-2 satellite imagery

WorldView-2 satellite was launched in October 2009 by DigitalGlobe [14]. Its orbit has an inclination of 97°.2 and is placed at an altitude of 770 km; its orbit period is 100 min. The revisited frequency is 1.1 days at nadir and 3.7 days at 20° off-nadir. The swath width, at nadir, is 16.4 km.

WorldView-2 satellite has two push-broom scanners that acquire: panchromatic and multispectral images[15].The former have a spatial resolution of 0.46 m, resampled to 0.50 m for commercial scope; the spectral interval is 0.450 μm – 0.800 μm.The multispectral images have a spatial resolution of 1.85 m, resampled to 2 m for commercial scope. The sensor acquires 8 bands: Coastal (0.400 μm – 0.450 μm); Blue (0.450 μm – 0.510 μm); Green (0.510 μm – 0.580 μm); Yellow (0.585 μm – 0.625 μm); Red (0.630 μm – 0.690 μm); Red Edge (0.705 μm – 0.745 μm); Near-IR1 (0.770 μm – 0.895 μm); Near-IR2 (0.860 μm – 1.040 μm).Both panchromatic and multispectral images have 11 bits as radiometric resolution. The higher spatial resolution as well as availability of 8 bands make WorldView-2 very useful for GIS applications. In fact they can integrate a geodatabase, so to contribute to define the different representations (scale, time) of the same geographic entities and relationships [16]as well as support object identification such as coastline [17] and horticultural greenhouses [18].

In this study WorldView-2 imagery concerning West area of Naples city (Fuorigrotta) was considered (Fig. 1). Dataset was acquired on 2011/06/26. It is georeferenced in the UTM/WGS84 33 N zone T coordinates system and it is included between coordinates EAST 431,220 m - 432,720 m and NORTH 4,518,884 m - 4,520,384 m.

B. Pan-sharpening methods

*1) IHS-Pan-sharpening:*IHS-Pan-sharpening falls intothe category of pixel level algorithms named Component Substitution techniques [19], [20].

In IHS-Pan-sharpening, multispectral images are projected from RGB (Red-Green-Blue) to IHS (Intensity-Hue-Saturation) color space[21]. In the new color space, "I" is comparable to the panchromatic image but not coincident with it. This difference is measured[22] by:

$$\delta = PAN - I \quad (1)$$

In literature there are several ways to calculate Intensity. In according to the fusion framework called Generalized IHS (GIHS) [23], it can be calculated by:

$$I = \frac{1}{l}\sum_{i=1}^{l} MS_i \quad (2)$$

where,

l represents the number of the multispectral bands.

Taking into account the spectral response of the MS and PAN sensors, weights for each multispectral images can be introduced. In this case Intensity is supplied by[22]:

$$I = \frac{1}{\sum_1^l \varphi_i}\sum_{i=1}^{l} \varphi_i \cdot MS_i \quad (3)$$

where,

$\varphi_i$is the weight of i-th multispectral band.

Fig. 1. Study area: WorldView-2 RGB composition

2) Brovey Transform: Brovey Transform(BT) was developed by an American scientist toincrease visually the contrast in the low and high ends of an image's histogram[24]. It is a combination of arithmetic operations and it needs to normalize the spectral bands before they are multiplied with the panchromatic. The BT will probably lead to color distortion especially when the spectral range of the input images are different or when they have significant long term temporal changes [25]. The fused R, G, and B images (MS_{out}) are defined by the following equations [26]:

$$MS_{out} = \frac{MS_i}{MS_{tot}} \cdot PAN \quad (4)$$

where,

MS_i is the i-th multispectral image;

MS_{tot} is the combination of the multispectral images.

MS_{tot}can be calculated using the following formulas[27]:

$$MS_{tot} = \frac{1}{n} \cdot \sum_{i=1}^{n} MS_i \quad (5)$$

or

$$MS_{tot} = \frac{\sum_{i=1}^{n} \varphi_i \cdot MS_i}{\sum_{i=1}^{n} \varphi_i}. \quad (6)$$

*3) Zhang:*The Zhang algorithm utilizes the least squares technique tofind the best fit between the grey values of the PAN band and the MS bands to adjust thecontribution of individual bands to the fusion result. It employs a set of statisticapproaches to estimate the grey value relationship between all the input bands to eliminatethe problem of data set dependency. In this way, the influence of data set variation in thefusion processis reduced [28].

The equation for fusing panchromaticand multispectral bands can be written as [29]:

$$MS_{out} = MS_i \cdot \frac{PAN_{orig}}{PAN_{syn}} \quad (7)$$

where,

MS_i is the i-ma multispectral images;

PAN_{orig} is panchromatic image;

$$PAN_{syn} = \sum_{i=1}^{n} \varphi_i \cdot MS_i. \quad (8)$$

C. Evaluation of pan-sharpening methods

To define the accuracy of pan-sharpened data is a problem because a reference image at the same resolution of the fused one does not exist. So, several methods to evaluate the quality of the pan-sharpened data are used. In this paper Correlation Coefficient (CC), ERGAS and UIQI indexes are used.

1) Correlation Coefficient: It measures the correlation between two images[30]. In pan-sharpening applications it compares original multispectral (MS) and fused images (MS'). Correlation Coefficient (CC) values close to one indicate that MS and MS' are correlated[9]. The CC is given by [31]:

$$CC(MS/MS') = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(MS_{i,j}-\overline{MS})\cdot(MS'_{i,j}-\overline{MS'})}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(MS_{i,j}-\overline{MS})^2\cdot\sum_{i=1}^{M}\sum_{j=1}^{N}(MS'_{i,j}-\overline{MS'})^2}} \quad (9)$$

where,

$\overline{MS}$ is the mean of the pixels of the original image;

$\overline{MS'}$ is the mean of the pixels of the fused image.

2)ERGAS: Erreur Relative Globale Adimensionalle de Synthèse quantifies the spectral quality of the different fused images [32]. The ERGAS index is given by [33]:

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

where,

h is the spatial resolution of reference image (PAN);

l is the spatial resolution of original multispectral images (MS);

N is the number of spectral bands;

RMSE is the Root Mean Square Error for k-band between fused (MS') and original bands (MS) [34];

$\mu_k$is the mean of the k-band of original image.

Low values of ERGAS suggest a likeness between original and fused bands.

3) UIQI: Universal Image Quality Index does not depend on tested images or viewing conditions or the individual observer; it is a product of three components [35]:

$$Q = \frac{\sigma_{xy}}{\sigma_x \cdot \sigma_y} \cdot \frac{2\bar{x}\bar{y}}{(\bar{x})^2+(\bar{y})^2} \cdot \frac{2\sigma_x\sigma_y}{\sigma_x^2+\sigma_y^2} \quad (11)$$

where,

x is the original band;

y is the fused image;

$\bar{x}$ and $\bar{y}$ are the means of x and y images;

σ_{xy} is the covariance between x and y images;

σ_x and σ_y are the standard deviation of x and y images;

σ_x^2 and σ_y^2 are the variances of x and y images.

The first component in Q formula is CC between two considered images; the second measures the mean shift between original and fused images;the third assesses the similarity of the contrast between the images. Values of Q close to 1 indicate a great result in pan-sharpening application [36], [37].

D. Application of pan-sharpening methods

To improve the WorldView-2 multispectral images spatial resolution (2 m),in accordance with panchromatic ones (0.5 m), the described pan-sharpening methods were used: IHS-Pan-sharpening, Brovey and Zhang.

In the IHS method,the component Intensity (I)was defined as [22]:

$$I = \frac{\varphi_1 \cdot B1 + \varphi_2 \cdot B2 + \varphi_3 \cdot B3 + \varphi_4 \cdot B4 + \varphi_5 \cdot B5 + \varphi_6 \cdot B6 + \varphi_7 \cdot B7}{\sum_{i=1}^{7} \varphi_i} \quad (12)$$

where,

φ_i are the coefficients associated to single bands;

B1 is Coastal band;

B2 is Blue band;

B3 is Green band;

B4 is Yellow band;

B5 is Red band;

B6 is Red Edge band;

B7 is NIR1 band.

Spectral response of WorldView-2 (Fig. 2) was used to define$\varphi_i$coefficients in (3), (6),(8) and (12).

III. RESULTS AND DISCUSSION

The accuracy of the pan-sharpened images (Fig. 3) was evaluated by the CC, ERGAS and UIQI. The resampled original multispectral image at the same panchromatic spatial resolution and the pan-sharpened multispectral image were compared. Table I reports the values of the used indexes; particularly, for CC and UIQI mean values are reported.

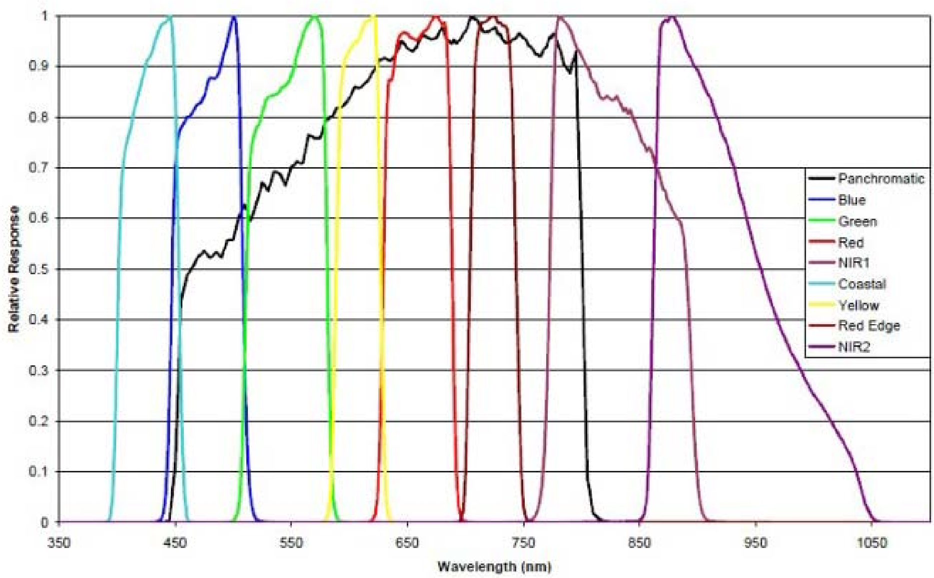

Fig. 2. WorldView-2 spectral response

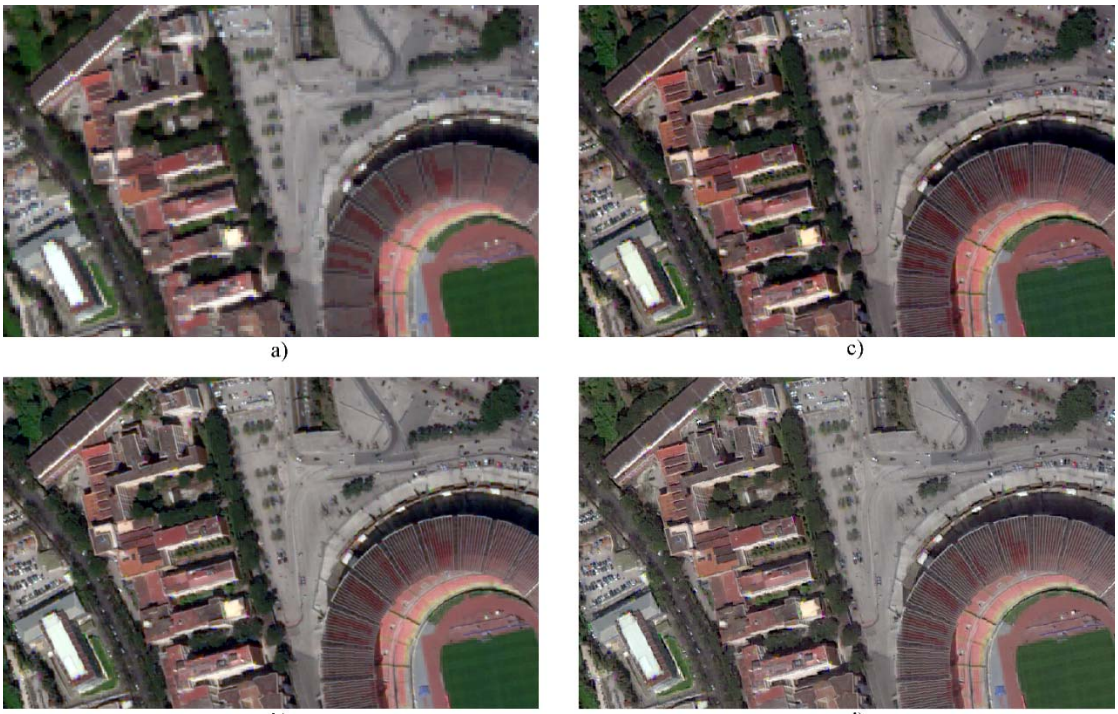

Fig. 3. Comparisonof the RGB compositions obtained with: a) original files; b) Brovey products; c) IHS products; d) Zang products

TABLE I. Values of Indexes Used to Evaluate Pan-sharpening Techniques

	CC	ERGAS	UIQI
Brovey	0.920	3.256	0.920
IHS	0.931	2.886	0.931
ZSVR	0.920	3.905	0.920

IHS pan-sharpening technique is the more powerful among three tested methods. It presents the lowest value of ERGAS (2.886) and the highest value of CC (0.931). Between the Brovey and the Zangmethods, the former is better than the latter: the first has an ERGAS value greater than the second. For the same method CC and UIQI have the same value on three digits.

IV. CONCLUSION

In this paper, three different pan-sharpening techniques were tested on WorldView-2 imagery. Values of indexes used to verify quality of fused images show that the use of the weights improves pan-sharpening results. In particular, these weights can be easily derived by spectral response. Because of the large acquisition range of PANband, 7 of the 8 multispectral images can be submitted to pan-sharpening. Even if the visual analysis confirms the high performance of all three considered methods, all indexes show that IHS technique results the better in this application.

ACKNOWLEDGEMENTS

The article was written in the context of the Research Projects of National Interest (PRIN2010-2011)"Innovative and emerging geomatics techniques of survey, remote sensing (by airplane, satellite, UAV) and WEBGIS for risk mapping in real time and the prevention of environmental damage" funded by MIUR (Ministero dell'Istruzione, dell'Università e della Ricerca).

REFERENCES

[1] L. Xin-zhi, W. Ping and Z. Yan-bin, "Application of SPOT 5 data fusion on investigating the ecological environment of mining area," in Proc. of the Urban Remote Sensing Event, 2009, pp. 1-6. E-ISBN: 978-1-4244-3461-9.
[2] B. Aiazzi, S. Baronti and M. Selva, "Improving component substitution pan-sharpening through multivariate regression of MS+Pan data,"IEEE Transactions on Geoscience and Remote Sensing, vol. 45(10), pp. 3230–3239, Oct. 2007. DOI:10.1109/TGRS.2007.901007.
[3] 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(4), pp. 743-757, 1998. DOI:10.1080/014311698215973.
[4] S. Rahmani, M. Strait, D. Merkurjev, M. Moeller and T. Wittman, "An Adaptive IHS Pan-Sharpening Method,"Geoscience and Remote Sensing Letters IEEE, vol. 7(4), pp. 746-750, May 2010. DOI: 10.1109/LGRS.2010.2046715.

[5] M. A. Aguilar, R. Vicente, F. J. Aguilar, A. Fernández and M. M. Saldana, "Optimizing object-based classification in urban environments using very high resolution GeoEye-1 imagery,"ISPRS Annals of thePhotogrammetry, Remote Sensing and Spatial Information Sciences, vol. I(7), pp. 99-104, Jul. 2012. DOI: 10.5194/isprsannals-I-7-99-2012.
[6] P. Maglione, C. Parente and A. Vallario, "High resolution satellite images to reconstruct recent evolution of domitian coastline,"American Journal of Applied Sciences, vol. 12(7), pp. 506-515, Jul. 2015. DOI: 10.3844/ajassp.2015.506.515.
[7] C. Meneghini and C. Parente, "A new index to perform shadow detection in GeoEye-1 images,"International Journal of Engineering and Technology, vol. 7(5), pp. 1581-1588, Oct.-Nov. 2015. ISSN: 0975-4024.
[8] O. R. Belfiore and C. Parente,"Orthorectification and Pan-Sharpening of WorldView-2 satellite imagery to product High Resolution Coloured ortho-photos,"Modern Applied Science, vol. 9(9), pp. 122-130,Sep. 2015 DOI: 10.5539/mas.v9n9p122.
[9] Q. Du,N. H. Younan, R. King and V. P. Shah, "On the performance evaluation of Pan-sharpening techniques,"Geoscience and Remote Sensing Letters IEEE, vol. 4(4), pp. 518-522, Oct. 2007. DOI:10.1109/LGRS.2007.896328.
[10] K. G. Nikolakopoulos, "Comparison of nine fusion techniques for Very High Resolution data,"Photogrammetric Engineering & Remote Sensing, vol. 74(5), pp. 647-659, May 2008. DOI: 10.14358/PERS.74.5.647.
[11] Y. Zhang and R. K. Mishra, "A review and comparison of commercially available Pan-sharpening techniques for High Resolution satellite image fusion," in Proc. of the Geoscience and Remote Sensing Symposium (IGARSS), 2012, pp. 182-185. DOI: 10.1109/IGARSS.2012.6351607.
[12] R. A. Mandhare, P. Upadhyay and S. Gupta, "Pixel-level image fusion using Brovey transform and Wavelet transform,"International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2(6), pp. 2690-2695, Jun. 2013. ISSN (Print): 2320-3765. ISSN (Online): 2278-8875.
[13] G. Palubinskas, "Joint Quality Measure for evaluation of Pansharpening accuracy,"Remote Sensing, vol. 2015(7), pp. 9292-9310, Jul. 2015. DOI: 10.3390/rs70709292.
[14] (2015) DigitalGlobe website - WorldView-2 datasheet [Online]. Available: https://www.digitalglobe.com/sites/default/files/DG_WorldView2_DS_PROD.pdf.
[15] P. Maglione, "Very High Resolution Optical Satellites: An Overview of theMost Commonly used," American Journal of Applied Sciences, vol. 13(1), pp. 91-99, Jen. 2016. DOI: 10.3844/ajassp.2016.91.99
[16] U. Falchi, "A Conceptual Model for the Management of Multi-Representation Geographical Information,"International Journal of Engineering and Technology, vol. 7(6), pp. 2060-2068, Dec 2015 - Jan. 2016. ISSN: 0975-4024.
[17] P. Maglione, C. Parente and A. Vallario, "Coastline extraction using high resolutionWorldView-2 satellite imagery," European Journal of Remote Sensing, vol. 2014(47), pp. 685-699, Oct. 2014. DOI: 10.5721/EuJRS20144739.
[18] M. A. Aguilar, A. Vallario, F. J. Aguilar, A. G. Lorca and C. Parente, "Object-Based Greenhouse Horticultural Crop Identification from Multi-Temporal Satellite Imagery: A Case Study in Almeria, Spain," Remote Sensing, vol. 7(6), pp. 7378-7401, Jun. 2015. DOI: 10.3390/rs70607378.
[19] C. Pohl andJ. L. Van Genderen, "Multisensor image fusion in remote sensing: Concepts, methods and applications,"International Journal of Remote Sensing, vol. 19(5), pp. 823-854, 1998. DOI: 10.1080/014311698215748.
[20] J. Zhang, "Multi-source remote sensing data fusion: status and trends,"International Journal of Image and Data Fusion, vol. 1(1), pp. 5-24, Feb. 2010.DOI: 10.1080/19479830903561035.
[21] Y. Zhang, "Understanding image fusion,"Photogrammetric Engineering & Remote Sensing, vol. 6: 657–661, Jun. 2004.
[22] 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,"Geoscience Remote Sensing IEEE, vol. 1(4), pp. 309-312, Oct. 2004. DOI: 10.1109/LGRS.2004.834804.
[23] T. M. Tu, S. Su, H. Shyu and P. S. Huang,"A new look at IHS-like image fusion methods,"Information Fusion, vol. 2(3), pp. 177-186, Sep. 2001. DOI: 10.1016/S1566-2535(01)00036-7.
[24] E. Saroglu, F. Bektas, N. Musaoglu and C. Goksel, "Fusion of multisensory sensing data: assessing the quality of resulting images,"ISPRS Archives, vol. XXXV(B4), pp. 575-579, 2004.
[25] R. Gharbia, A. H. El Baz, A. E. Hassanien and M. F. Tolba, "Remote sensing image fusion approach based on Brovey and Wavelets transforms,"Advances in Intelligent Systems and Computing, vol. 303, pp. 311-321, 2014. DOI: 10.1007/978-3-319-08156-4_31.
[26] B. Johnson, "Effects of Pansharpening on Vegetation Indices,"ISPRS International Journal of Geo-Information, vol. 2014(3), pp. 507-522, Apr. 2014. DOI:10.3390/ijgi3020507.
[27] C. Parente and R. Santamaria, "Increasing geometric resolution of data supplied by Quickbird multispectral sensors,"Sensors & Transducers, vol. 156(9): 111-115, Sep. 2013.
[28] Y. Zhang andR. K. Mishra "From UNB PanSharp to Fuze Go – the success behind the pan-sharpening algorithm,"International Journal of Image and data Fusion, vol. 5(1), pp. 39-53, Nov. 2013. DOI: 10.1080/19479832.2013.848475.
[29] Y. Zhang,"System and method for image fusion," U. S. Patent 2004/0141659 A1, Jul- 22, 2004.
[30] V. Meenakshisundaram, "Quality assessment of IKONOS and Quickbird fused images for urban mapping,"University of Calgary, Department of Geomatics Engineering, UCGE Tech. Rep. 20224, 2005.
[31] V. Vijayaraj, C. G. O'Hara and N. H. Younan, "Quality analysis of pansharpened images,"in Proc. of the Geoscience and Remote Sensing Symposium IGARSS '04, 2004. DOI: 10.1109/IGARSS.2004.1368951
[32] M. Lillo-Saavedra, C. Gonzalob, A. Arquerob and E. Martinez, "Fusion of multispectral and panchromatic satellite sensor imagery based on tailored filtering in the Fourier domain,"International Journal of Remote Sensing, vol. 26(6), pp. 1263-1268, Dic. 2004. DOI: 10.1080/01431160412331330239.
[33] B. Aiazzi, S. Baronti and M. Selva, "Image fusion through multiresolution oversampled decompositions,"in Image Fusion: Algorithms and Applications, New York:Academic, pp. 27-66, 2008.
[34] S. D. Jawzk and A. J. Luis, "A spectral index ratio-based Antarctic land-cover mapping using hyperspatial 8-band WorldView-2 imagery,"Polar Science, vol. 7(2013), pp. 18-38, Mar. 2013. DOI: 10.1016/j.polar.2012.12.002.
[35] Z. Wang and A. C. Bovik, "A universal image quality index,"Signal Processing Letters IEEE, vol. 9(3), pp. 81-84, Mar. 2002. DOI: 10.1109/97.995823.
[36] L. Alparone, S. Baronti, A. Garzelli and F. Nencini, "A global quality measurement of pan-sharpened multispectral imagery,"Geoscience and Remote Sensing Letters IEEE, vol. 1(4), pp. 313-317, Oct. 2004. DOI: 10.1109/LGRS.2004.836784.
[37] K. Nikolakopoulos and D. Oikonomidis, "Quality assessment of ten fusion techniques applied on Worldview-2,"European Journal of Remote Sensing, vol. 48, pp. 141-167, Jun. 2015. DOI: 10.5721/EuJRS20154809.

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