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APPLICATION OF DIFFERENT PAN-SHARPENING METHODS ON WORLDVIEW-3 IMAGES

Oscar Rosario Belfiore, Claudio Meneghini, Claudio Parente and Raffaele Santamaria
Department of Sciences and Technologies, University of Naples "Parthenope", Centro Direzionale, Isola C4, Naples, Italy
E-Mail: claudio.parente@uniparthenope.it

ABSTRACT

In the field of the remote sensing, the introduction of high resolution satellite sensors has required the development of several data fusion approaches. Two kinds of images are usually acquired: multispectral and panchromatic. The first group has a lower spatial resolution but accurate spectral information while the second presents a higher spatial resolution with a longer band acquisition range. Pan-sharpening permits to combine panchromatic and multispectral data to create new multispectral images with higher geometric resolution. In this paper nine different pan-sharpening methods are tested on WorldView-3 images: Brovey, Weighted Brovey, Gram Schmidt, IHS, Fast IHS, Multiplicative, Principal Component Analysis (PCA), Simple Mean and Zhang. With the aim to rank the techniques efficiency, visual inspections combined with quantitative evaluations are performed to test spectral qualities of the fused images. This is a difficult task because the quality of the fused image depends on the considered datasets: RMSE (Root Mean Square Error) and ERGAS (Relative Dimensionless Global Error) are the accuracy indices used for this scope.

Keywords: data fusion, pan-sharpening, quality assessment, very high resolution images, world view-3.

INTRODUCTION

Nowadays remote sensing applications necessitate of very high spatial and spectral resolution imageries. Using pre-processing techniques, such as orthorectification and shadow removal [1], it is possible to improve complex tasks such as urban and land cover classification [2] and color ortho–photos production [3].

Several satellites technical limits, such as restricted storage dimensions, limited data transfer speed and insufficient energy autonomy, represent serious problems that bar possibility to acquire at the same time high spatial and spectral resolution images: the most effective solution is to develop effective image fusion techniques [4].

Pohl and Van Genderen [5] classify those techniques in three levels:

- Pixel level fusion;
- Feature level fusion;
- Decision level fusion.

Zhang [6] gives an exhaustive explanation for all of them. In the first level data of many sources are combined into single resolution data, more informative and synthetic than the original data. The second level consists in extracting and combining features from different sources into one or more features map: it is very convenient when it is not possible to evaluate all bands individually; input images characteristics determine methods to apply for features extractions. The third level is a combination of the outputs of several algorithms to produce a final fused decision: it is called soft fusion if results are expressed as confidences otherwise hard fusion because outputs are represented as decisions.

Within the first group are included pan-sharpening methods that permit to transfer the higher geometric resolution of the pan images to the multispectral ones.

In this paper nine different pan-sharpening methods are applied to World View 3 (WV-3) satellite imagery. This manuscript is organized as follows. Section "Data and methods" illustrates both the characteristics of the WorldView-3 images and the application of some pan-sharpening algorithms. Visual and analytical evaluations of the fused images are discussed in the following section. Considerations and conclusions are summarized at the end of the paper.

DATA AND METHODS

WorldView-3 images

Successfully launched by DigitalGlobe on August 13, 2014, WorldView-3 (WV-3) (Figure-1) is the first multi-payload, super-spectral, high-resolution commercial satellite sensor. It has sun-synchronous orbit and sensors have a swath width of 13.1 km. Operating at an altitude of 617 km, it has an average revisit time less than 1 day: it daily collects up to 680,000 km^2. In addition to the standard Panchromatic and Multispectral bands, WorldView-3 has 8 short-wave infrared (SWIR) bands and 12 CAVIS ones (useful to provide information about atmospheric aerosols, water vapor and other components). Panchromatic and multispectral scenes have a dynamic range of 11 bit while the radiometric resolution for the SWIR is 14 bit [7].

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WorldView-3 provides the following geometric resolutions:

- 0.31 m for the panchromatic band;
- 1.24 m multispectral bands;
- 3.7 m for the short wave infrared bands;
- 30 m for the CAVIS bands.

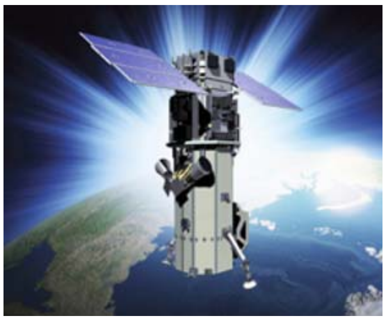

Figure-1. WV-3 satellite (Property of Digital Globe).

WV-3 satellite represents an incremental improvement compared to the previous WorldView-2 because it carries on-board also sensors with multispectral SWIR capability. The SWIR bands are useful in several applications: surface compositional modelling, mapping of rock and soil exposures. Other potential applications can be improved: geologic mapping, environmental/soil disaster monitoring, exploration for petroleum, minerals and geothermal resources [8]. Cost savings, risk reduction and faster delivery for customers are the most important benefits derived by WorldView-3 satellite sensor [9].

The images used for this work, provided by European Space Imaging (ESI) Company, were acquired on 6th June 2015 at 10:35 (UTC) by WV-3 satellite. It represents the zone around Groul, located in the region Baden-Wurttemberg in Germany. The bands used are both Panchromatic and Multispectral (Coastal, Blue, Green, Yellow, Red, Red Edge, Near Infrared-1 and Near Infrared-2). In Table-1 multispectral bands ranges are reported.

Table-1. The WV-3 multispectral bands.

Band	**Min band edge** (nm)	**Centre wave** (nm)	**Max band edge** (nm)
B1 -Coastal	400	425	450
B2 - Blue	450	480	510
B3 - Green	510	545	580
B4 - Yellow	585	605	625
B5 - Red	630	660	690
B6 - Red Edge	705	725	745
B7 - NIR1	770	835	895
B8 - NIR2	860	950	1040

From this scene a clip is extracted (Figure-2): it extends 1714.80 m x 1455.60 m (UTM/WGS84 plane coordinates – 32N zone: E_1 = 482510.4 m, N_1 = 5355422 m, E_2 = 484225.2 m, N_2 = 5353966.8 m). The selected area has a heterogeneous character: buildings, roads and different kinds of vegetation including trees dominate the scene.

Figure-2. RGB composition of the considered area.

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Pan-sharpening methods

The diagram in Figure-3 explains the procedures implemented in this work.

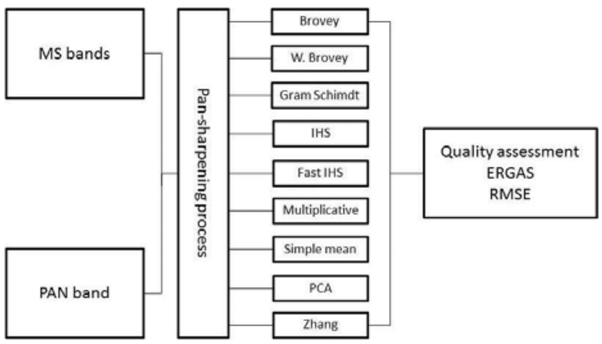

Figure-3. Workflow of the fusion and evaluation processes.

The first step consists in processing images by using the following pan-sharpening algorithms:

- Brovey [10];
- Weighted Brovey (W. Brovey)[11];
- Gram-Schmidt (GS) [12];
- Intensity Hue Saturation (IHS) [13];
- Fast IHS [14];
- Multiplicative (MLT) [15];
- Simple Mean (SM) [16];
- Principal Components Analysis (PCA) [17];
- Zhang [18].

Analyzing the spectral response of the WV-3 (Figure-4), it is necessary to determine weights for each band to use some of the above mentioned methods. Unlike the other bands, NIR2 curve doesn't have intersection with the corresponding panchromatic. For this reason, NIR2 is excluded from pan-sharpening process because its weight is equal to 0. In accordance with [19], a spreadsheet about WV-3 response curve, kindly provided by Apollo Mapping, is used to calculate the minimum value of the intercepted radiance (IntRad) between the panchromatic and multispectral bands for every wavelength interval. The IntRad sum for each band is divided for the IntRad sum of all bands: in this way weights are calculated and showed in Table-2.

Table-2. WV-3 multispectral band weights.

B1	B2	B3	B4	B5	B6	B7
0.005	0.142	0.209	0.144	0.234	0.157	0.116

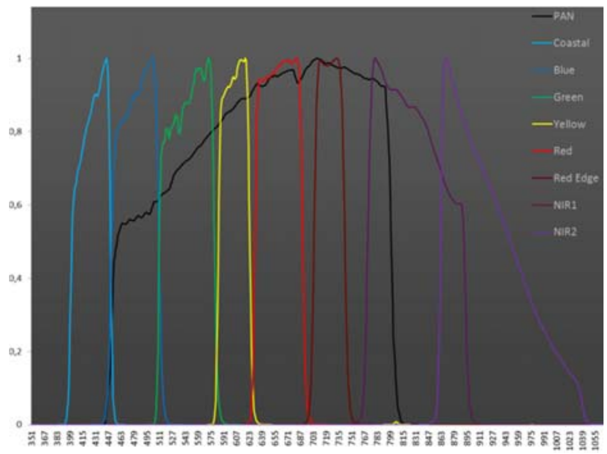

Figure-4. Spectral response of the WV-3 panchromatic and multispectral bands.

Most of the considered pan-sharpening methods are already discussed in [20]. These data fusion methods are reviewed in literature by different researchers too [21, 22, 23].

Santurri *et al.* [24] assert that PCA and IHS methods are highly sensitive to bands misalignment for VHR imageries. Zhang [25] says that with Brovey transform the pixel grey values are smaller than those of other fusion techniques: the colour distortion is evident and differs depending on the band combinations fused. Mandhare *et al.* [26] highlight the advantages and disadvantages of the multiplicative algorithm: the strength consists in its straightforward and simple character; the weakness is due to the new spectral bands with a higher correlation (it means the spectral characteristics of the original image data are altered). Du *et al.* [27] state that multiplicative technique, for the absence of normalization term, meaningfully changes the dynamic range of pixel values. Pohl and Van Genderen [10] declare that IHS offers a controlled visual presentation of the data. Zhang [18] asserts its method employs a set of statistic approaches to estimate the grey value relationship between all the input bands to limit radiometric distortion. For Shah *et al.* [28] the first PC image, having the highest variance, is the ideal choice to replace the high spatial resolution panchromatic image because it contains the most amount of information from the original image. Maurer [29] affirms that Gram-Schmidt method is more robust to spatial misalignment of the bands than most other pan-sharpening methods because all transform coefficients are computed in the low MS resolution. Rokni *et al.* [30] prefer Gram-Schmidt method because of its results on

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both edge detection and visual interpretation: it preserves the spectral quality in the fused images.

RESULTS

RGB compositions with the pan-sharpened images (B5, B3, B2) obtained by the application of above mentioned methods are shown in Figure-5.

The goal of the second step is to evaluate the radiometric accuracy of each algorithm using two quality indices:

- ERGAS (Relative Dimensionless Global Error [31];
- RMSE (Root Mean Square Error).

Considering results about ERGAS (Table 3) it is clear how Gram-Schmidt performs better than the other methods: its value is very low and it means that pan-sharpening is very reliable. The colours of the composite RGB pan-sharpened bands are almost identical to the corresponding original images. The methods which use weights (Fast HIS and W.Brovey) have a higher performance than original ones. Zhang method, performing matching histograms between the pan-sharpened images and the corresponding original ones, permits to get a good output. MLT and SM are the worst methods: they give unacceptable results. For what concerns RMSE index (Table-4), Gram-Schmidt maintains the primacy. The next positions are occupied by Fast IHS and W. Brovey methods: the quality of the final products is absolutely satisfactory; results degrade if weights are not introduced. Once again, PCA, SM and MLT prove their inadequacy for this kind of images; quality metrics aside, it is possible to see how their RGB compositions are so dissimilar from the original ones. In fact PCA doesn't perform well too because its RGB compositions is very close to the green; SM generates a contradictory RGB composition due to the strong presence of brown tonalities; MLT produces RGB composition too much darker than original ones.

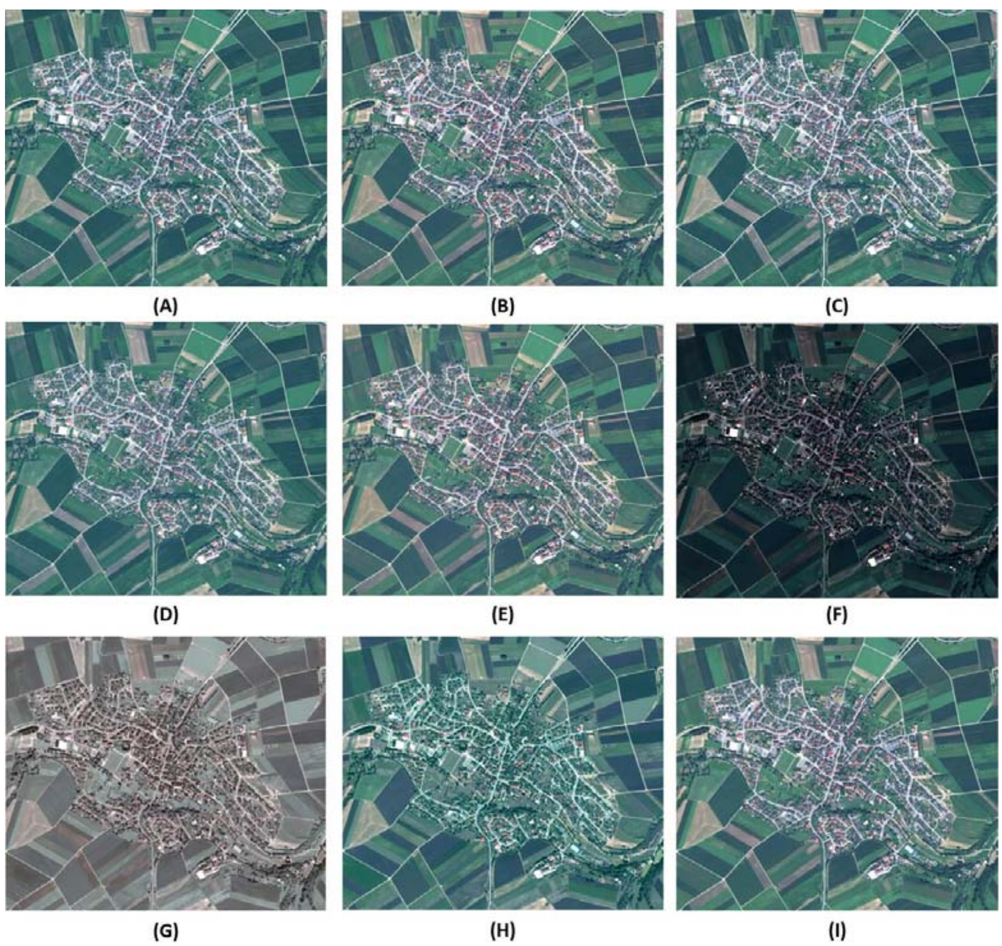

Figure-5. RGB compositions of the images derived by the following methods: (a) Brovey, (b) W. Brovey, (c) Gram-Schmidt, (d) IHS, (e) Fast IHS, (f) Multiplicative, (g) Simple mean, (h) PCA, (i) Zhang.

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Table-3. ERGAS index values for the adopted pan-sharpening methods.

ERGAS								
GS	**W. Brovey**	**Brovey**	**Zhang**	**Fast IHS**	**IHS**	**PCA**	**MLT**	**SM**
2.38	*3.17*	*3.40*	*3.44*	*3.60*	*3.95*	*7.26*	*22.6*	*23.9*

Table-4. RMSE values for the multispectral pan-sharpened images.

RMSE									
Bands	**GS**	**Fast IHS**	**W. Brovey**	**IHS**	**Brovey**	**Zhang**	**PCA**	**SM**	**MLT**
Coastal	6.18	31.10	22.67	34.34	23.57	11.53	12.25	210.17	117.98
Green	10.68	31.46	22.02	34.55	23.20	17.99	17.18	223.75	153.17
Blue	21.29	32.05	29.09	34.88	31.02	27.96	13.76	195.87	217.47
Yellow	23.07	32.04	30.55	34.89	32.45	34.97	30.27	204.41	231.11
Red	22.36	32.07	29.38	34.89	31.40	38.75	48.29	222.65	233.92
Red Edge	39.91	32.05	35.77	34.89	39.370	38.33	142.58	125.15	229.52
NIR1	74.02	32.08	63.33	34.90	74.99	86.75	457.60	168.34	290.11
	28.21	*31.83*	*33.26*	*34.76*	*36.57*	*36.62*	*103.13*	*192.90*	*210.47*

CONCLUSIONS

In this paper nine data fusion algorithms have been evaluated on Worldview-3 data, both Panchromatic and Multispectral. The size of the considered dataset is 16,360 x 10,576 pixels. Data fusion techniques increase the geometric resolution of the new images: it follows that detection of small objects, like cars, buildings and trees becomes easier. Although the spatial resolution of the resultant images is improved compared to the original ones, the same reasoning is not valid for the radiometric resolution.

This work confirms that all the pan-sharpening methods have different performances: qualitative and quantitative analyses are necessary because they sometimes can provide contradictory results. By a first visual examination, colours of the all fused images look like natural except PCA, SM and MLT methods. For the second kind of study, two quality indices are used to evaluate quality assessment of the fused images: the majority of the algorithms produce very good results for ERGAS and RMSE. MLT and SM methods are low computationally complex and easily implemented, but unsuitable because of radiometric distortion of the results. The GS algorithm results in this work the most efficient method. The introduction of weights in Brovey and IHS produces better outcomes.

All pan-sharpening methods permit to improve spatial information of the multispectral images, but only if the new radiometric values are reliable the resulting dataset can be correctly used for remote sensing applications.

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