Remote Sensing in Transition, Goossens (ed.)

Fusion of Quickbird MS and Pan data for urban studies

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Keywords: fusion methods, comparison, urban features

ABSTRACT: Most of the satellite sensors, presently operating in the optical domain, are providing a data set comprising multispectral images at a low spatial resolution and images at a higher spatial resolution but with a lower spectral content. The trend of satellite sensors is similar to the present situation. The idea of fusing multispectral images with a highest spatial resolution enables the creation of useful products for urban planning and management. This paper aims at evaluating two methods for construction of synthetic multispectral images having a highest spatial resolution available within the data set, in the objective of studying urban areas. The first one is derived from the ARSIS concept and the second one is based on a correlation technique. The two methods are described and tested over the urban area of Strasbourg (France). The resulting images are evaluated through visual, qualitative and quantitative criteria. Some conclusions are drawn on the difference between the two algorithms and on the benefits of their use in urban studies.

1 INTRODUCTION

The Very High Resolution (VHR) satellite such as Quickbird, provides sub-meter spatial resolution images in the panchromatic mode and four multispectral images with a spatial resolution four times coarser than the panchromatic band.

Such data are a benefit in the context of complex urban areas where the relatively small size and complex spatial pattern of the component scene elements (e.g. buildings, roads and intra-urban open areas) have restricted the use of the current space borne sensors (Barnsley and Barr 1997). Indeed, the urban environment heterogeneity requires an adapted fine spatial and spectral resolution (Puissant and Weber, 2002). VHR data give access to very precise information for urban analysis but increase the amount of information available on land cover at local and national scales (Aplin et *al.* 1997).

The multiplication of details lead to develop new processing methods combining geometric and radiometric criteria (Puissant *et al.*, 2003) Indeed, these latter influence the ability to analyse different types of urban structure. The geometric criteria include surfaces, shapes and organisation of the objects and the radiometric criteria include specific reflectance of the constitutive elements of the objects.

The benefit of obtaining multispectral images with the highest spatial resolution available has been clearly demonstrated, particularly for vegetation, land-use and urban studies (Couloigner *et al.* 1997, 1998a, b; Raptis *et al.* 1998; Vaiopoulos *et al.* 2001; Wald and Ranchin 2001). On the one hand, the high spatial resolution is necessary for an accurate description of the shapes, features and structure. On the other hand, depending on the application and the level of land cover complexity, the different types of land-use are better classified if spectral resolution images are used. Hence, there is a request to combine the high spatial and the high spectral resolutions with the aim of obtaining the most complete and accurate description of the observed data, especially in urban analysis.

This paper aims at evaluating two methods for construction of synthetic multispectral images having a highest spatial resolution available within the data set, in the objective of studying urban areas. The first one is derived from the ARSIS concept (Ranchin and Wald, 2000) and the second one is based on a correlation technique (Serradj *et al.*, 1991). The second section presents the end-user needs for urban studies while the third presents the study area. The two methods are briefly described in the fourth section. The fifth section presents a comparison of the two methods. Several aspects are assessed: visual, qualitative and quantitative criteria. Finally some concluding remarks are drawn on the benefits of the two fusion processes in urban studies.

2 END-USER NEEDS IN URBAN AREAS

Urban analysis is a complex domain due to multiple interactions between the social, politic and environmental spheres. The field of urban development is thus composed of different types of applications: firstly daily management of the territory (network, facilities and green spaces), secondly, urban planning (operational planning, impact study, regulations documents) and finally urban prospective (development scenario). All these applications require access to reliable up-to-date data and a good knowledge of the land cover and its evolution.

Currently the domain of planning and urban analysis is characterized by multi-criteria decision-making, which is typically very sensitive to context (Mesev *and al.,* 2000). These requirements lead the end-users to combine multisource information at various scales (French Equipment Ministry, 1999). In this context, Earth Observation Data (aerial or satellite) are a potential source of information, but seldom used by urban planners (Galaup and de Boissezon, 1997). Results of surveys of potential end-user requirements (Puissant and Weber, 2001) have shown that currently the main applications in urban areas concern the tactical and technical levels for which 1:200 to 1:10,000 scales are needed (Table 1).

Table 1. End-user needs in urban applications and image data

Applications	Scales	Resolution	Images data*
Operational level:			
- Technical management	1:200 to 1:500	20 cm	Orthophoto
- Basic mapping	1:1000 to 1:2000	20 to 50 cm	Orthophoto
Tactical level: Planning	1:5000 to 1:10,000	50 to 1 m 1 to 5 m	Orthophoto, Ikonos-2 Quickbird-2, SPOT5, *Orbview-3*
Strategic level: Prospective	1:10,000 to 1:1,000,000	> 5 m 10 to 30 m	IRS, SPOT, Landsat Quickbird-2, SPOT5, *Orbview-3*

* current satellite and *future satellite*

For these applications, the most useful source of image data is aerial photography. In fact, sub-meter resolution orthophotos are the only image used (Puissant and Weber, 2002). As satellite images did not achieved better resolutions than the 5.8 m of the IRS sensor (except Ikonos and Quickbird which are too expensive for many planning agencies), these data were only used for 1:25,000 to 1:1,000,000 scales applications. Indeed, for this old generation of so-called "High Resolution" satellite sensor (with a spatial resolution of more than 5m), basic urban objects are commonly smaller than the size of the image pixels. For the new generation, the so-called "Very High Resolution" of satellite sensors (Fritz, 1996), which produce digital image data with a spatial resolution of 0.61 to 5 m (Ikonos launched in 1999, Quickbird in 2001, and SPOT 5 in 2002), urban objects are typically larger than the image pixels. These new sensors with resolutions similar to aerial photography can identify urban objects. These resolutions enable the analysis of the spatial pattern of cities at scales between 1:10,000 and 1:25,000, typical of projects dealing with urban planning (Donnay *et al.*, 2000).

It is anticipated that relevant imagery products will be used if their performance has been assessed. Two main milestones have to be successfully overcomed: (1) the assessment of identification capacity through satellite imagery products for urban analysis and (2) the enhancement of classification methods enabling the understanding of the studied urban space. The first point requires precise and sharp location, the second knowledge-based inputs for classification methods. Regarding the first step fused documents might provide such confidence in satellite imagery products if spectral and geometric qualities are preserved.

3 STUDY AREA AND DATA USED

The study area is the urban agglomeration of Strasbourg (France). This area is representative of the urban structure of western cities and is characterised by many different objects (e.g. buildings, streets, water, parks, gardens) that exhibit a diverse range of spectral reflectance values and shapes.

The Quickbird images (acquired in May 2002) with a spatial resolution of 2.8 m in four bands (B0: 0.45-0.52 µm, B1: 0.52-.60 µm, B2: 63-0.69 µm and B3: 0.76-.90 µm) and the panchromatic mode with a spatial resolution of 0.7m (P: 0.45-0.90 µm) are used in their full dynamic range (11 bits coded in 16 bits) to test and compare the two fusion algorithms.

Urban features referring to the land cover theme have been selected to be used in the qualitative assessment. They regroup the following basic themes: trees, grass, building, road -asphalt, water. A shadow theme has been added, as it is largely present in such resolution.

4 TWO ALGORITHMS FOR THE FUSION OF MS AND P IMAGES

The first algorithm of data fusion is derived from the ARSIS concept (Ranchin and Wald, 2000) and the second one is based on a correlation algorithm (Serradj *et al.*, 1991).

4.1 *The ARSIS algorithm*

This algorithm makes use of a multi-scale approach and of high quality transformation of the information of the panchromatic image of Quickbird. The algorithm used for the implementation of the ARSIS concept is the so-called UWT-M2 (Ranchin and Wald, 2003). It makes use of an undecimated wavelet transform and to the Inter Modality Model called M2.

Figure 1 details the ARSIS concept application with a spatial resolution ratio of 4. The set of images is composed of a panchromatic image *P* at the best normalised spatial resolution *1* and multispectral images B_i a the normalised spatial resolution of *4*. The spatial resolution is normalised to a value without unit for simplification of the presentation. The fusion process is applied on each image of the multispectral set. In this case the multi-scale algorithm used is the one proposed by Dutilleux (1989). In this algorithm, a single scale function is used. The approximation of the original image is obtained by filtering of the original image and the wavelet coefficient image by subtracting, on a pixel basis, of the original image and its approximation. This algorithm delivers for each iteration, an approximation and a non-directional wavelet coefficients images. The resolution change is obtained by dilation of the scale function, obtained by introduction of a zero between each filter coefficient. The image is never resampled and all the images have the same sizes in pixel. The reconstruction step is achieved by a simple summation of the last approximation and of all wavelet coefficients images.

The multi-scale algorithm used for implementation of the ARSIS concept to the ratio of spatial resolution 4 is derived from this algorithm.

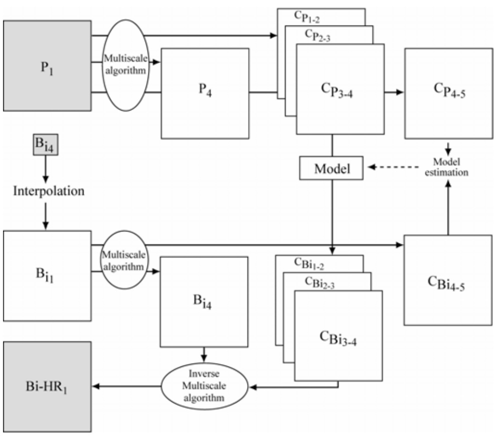

Figure 1. Application of the ARSIS concept with a spatial resolution ratio of 4

4.2 *The correlation algorithm*

The second fusion algorithm tested is the correlation coefficients method. It is based on the correlation coefficient between the panchromatic band and the multispectral band concerned (Serradj *et al.*, 1991). The algorithm used for Quickbird images is:

$$QBmp_n(x,y) = QBm_n(x,y).coef_n + QB_p(x,y).(1-coef_n) \quad (1)$$

where $QBmp_n(x,y)$ = Pan-sharpened pixel for band n; $QBm_n(x,y)$ = Digital Number for multispectral Quickbird band n; $QB_p(x,y)$ = Digital Number for panchromatic Quickbird band and $coef_n$ = Correlation coefficient between the panchromatic and the multispectral band n.

Several equations have been tested for the Correlation method (Figure 2). The large range of panchromatic values of the Quickbird image (0.45 – 0.90 µm) and its strong correlation with the near-infrared band has led to used the inverse relation in order to reduce the importance of the panchromatic band:

$$QBmp_n(x,y) = (QBm_n(x,y).(1-coef_n)) + (QBp(x,y).(coef_n)) \quad (2)$$

where $QBmp_n(x,y)$ = Pan sharpened pixel for band n; $QBm_n(x,y)$ = Digital Number for multispectral Quickbird band n; $coef_n$ = Correlation coefficient between the panchromatic and the multispectral band n.

The analysis of the means and the correlation in Figure 2 prove that the best fusion method, where fused image is statistically closest of the original image, is the inverse relation (2).

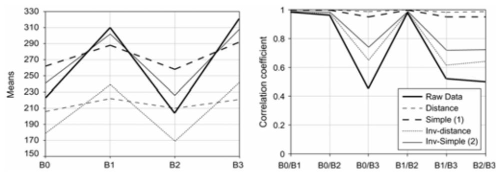

Figure 2. Test on fusion by correlation

5 COMPARISON OF THE SYNTHESISED IMAGES

For each method, the image synthesized with the ARSIS concept and the Correlation method are presented in Figure 3 while the original multispectral and panchromatic images are presented as references. The images extracts present a typical urban fabric of housing blocks.

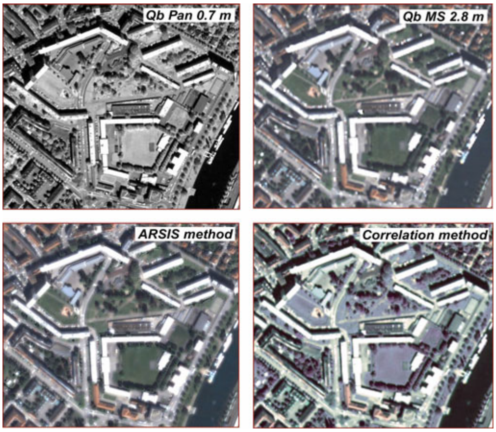

Figure 3. Extract of the original MS and P Quickbird images and results of the fusion methods (natural color composition)

In the following sections, the fusion results are firstly compared by a visual and qualitative assessment and secondly by statistical indicators.

5.1 *Visual comparison and qualitative assessment of the urban objects responses*

A visual interpretation of several urban objects identified in the synthesised images at 0.7 m computed from our set of images has been performed. In order to help the reader to the interpretation of the results only a zoom of a typical housing fabric is displayed in Figure 3. This example allows to understand the effects of the two algorithms.

In the case of the Correlation method, it is obvious that Figure 3 presents an artificial color, especially for the vegetation objects. The image result derived from the ARSIS concept is more stable and close to the original colors. To understand and explain these remarks, a qualitative assessment through radiometric cross-sections and dispersion graphs (analysis of the behaviour of the objects through the different bands) is performed for each method. This analysis is realized on various urban objects: three types of buildings' roofs with materials are chosen (tiles, gravels and metal/steel roofs); vegetation elements like trees and grass, some concrete surfaces (roads) and water surfaces; and a shadow class as it constitutes a permanent element in urban areas.

Four radiometric cross-sections have been realised over a set of urban objects in order to assess the behaviour of these elements in the four bands. Figures 4 and 5 represent two of these cross-sections.

They cross a distance of 140 m (200 pixels) and are composed of about ten elements gathering a maximum of five categories of urban elements categories.

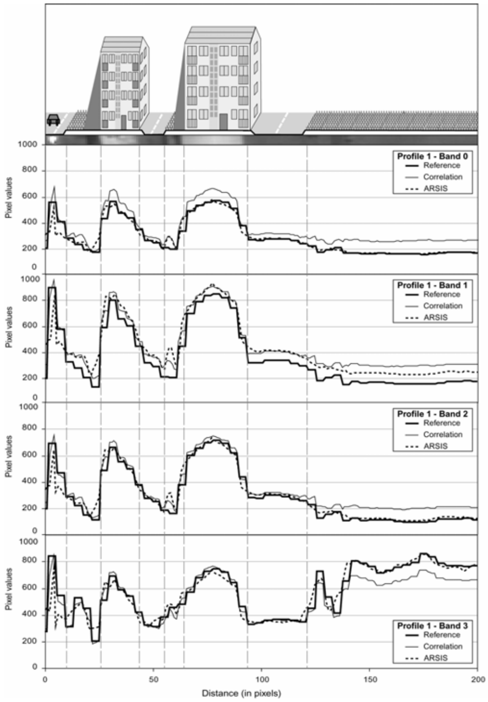

Figure 4. Radiometric cross-section 1

The radiometric values are represented for each urban object and for each band in Figures 4 and 5 (reference images, pan-sharpened image by ARSIS and by Correlation). The values of the pan-sharpened images for the crossed urban elements might be above, under or equal to the reference data. The statistics on these three curves allow to assess qualitatively the quality of the spectral behaviour for the various elements whatever the channel.

The results show that ARSIS method provides a good quality of image (equal to the original) for all the selected elements. The Correlation method provides good results only for three categories: the roads, the water surfaces and the shadows.

To complete this analysis, on the one hand, the most recurrent spectral behaviour (band by band) for each type of urban objects is assessed, and on the other hand, the estimated values of the pan-sharpened images are compared to the reference values (Figure 6).

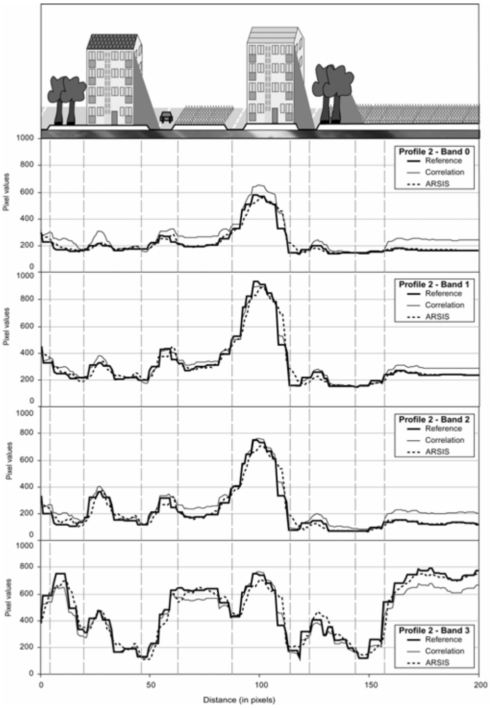

Figure 5. Radiometric cross-section 2

The Correlation method overestimates grass and trees in channels 0, 1, 2, underestimates them in channel 3. Water surfaces and shadow are inversely taken into account. For the steel and the gravel roofs and the roads, an overestimation is provides in channels 0 and 1, as they are correctly provided in channels 2 and 3.

ARSIS method provides better results in general. All categories are well rendered in channel 0, 2, and 3. But an overestimation for vegetation and water surface can be observed in channel 3.

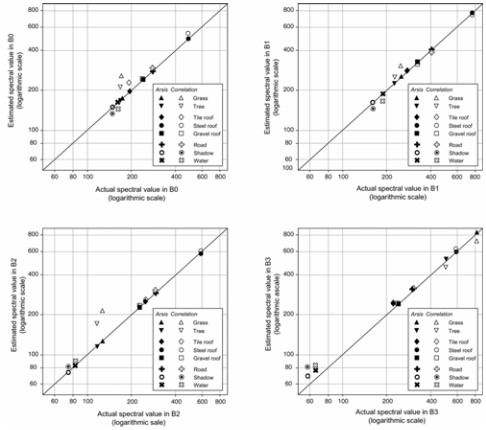

Figure 6. Comparison between actual and estimated spectral values

5.2 *Statistical comparison of the two fusion algorithms*

The statistical evaluation of the synthesised images is performed following the protocol proposed by Wald *et al.* (1997). All the computations are made on the full dynamic range of images (11 bits). These fusion products are synthetic images aiming at simulating what a sensor having the same spectral bands but the highest spatial resolution would observe.

The properties of these synthetic images B^*_h have been established by Wald *et al.* (1997):

- Any synthetic image B^*_h once degraded to its original resolution l, should be as identical as possible to the original image B_l.
- Any synthetic image B^*_h should be as identical as possible to the image B_h that the corresponding sensor would observe with the highest spatial resolution h, if existent.
- The multispectral (or multi-modality) set of synthetic images B^*_h should be as identical as possible to the multispectral (or multi-modality) set of images B_h that the corresponding sensor would observe with the highest spatial resolution h, if existent.

As an illustration, Table 2 presents the test of the second property and reports some statistics on the relative discrepancies between the original images B_{kl} and the images B^*_{kl}. The differences are computed on a pixel basis and one image of differences is obtained per spectral band k. From each image of differences, the mean value (bias) and the standard deviation are computed. The bias represents the difference between the means and the original and the synthesised image; the standard deviation globally represents the level of error for any pixel. These quantities are expressed in percent relative to the mean radiance value of the original image B_{kl}. The ideal value for these parameters is 0.

In addition, the difference between the variance of the original image B_{kl} and that of B^*_{kl} is computed. It is expressed in percent relative to the variance of the original image. It expresses the quantity of information added or lost during the enhancement of the spatial resolution. Ideally, this value should be zero.

The correlation coefficient between the original image B_{kl} and B^*_{kl} is also computed. The ideal value is 1.

Table 2. Statistics on the synthesised images

		Bias	Standard Dev.	Diff. in Variance	Correlation Coeff.
Blue (B0)	Correlation	-11.3	29.4	-7.6	0.793
	UWT-M2	-0.02	25.4	-14.2	0.852
Green (B1)	Correlation	1.25	34.5	22.8	0.700
	UWT-M2	0.03	29.9	-19.7	0.860
Red (B2)	Correlation	-20.7	42.6	15.9	0.797
	UWT-M2	-0.23	40.1	-17.6	0.848
NIR (B3)	Correlation	2.8	44.8	17.8	0.646
	UWT-M2	-0.14	32.2	-20.7	0.851

Some statistics of the relative differences and the relative difference in variance (all in percent) and the correlation coefficient between the original and synthetised images for the spectral bands. See text for more explanations

Some remarks can be extracted from the analysis of Table 2. First of all, for the UWT-M2 (ARSIS) method, the bias appears very small as the Correlation method introduces a strong bias in all bands. The standard deviations are comparable for the two methods, but are always lower for the UWT-M2 method. The correlation coefficients are better for the UWT-M2 method than for the Correlation method. These statistics can be completed by a variance and a correlation analysis (Figure 7).

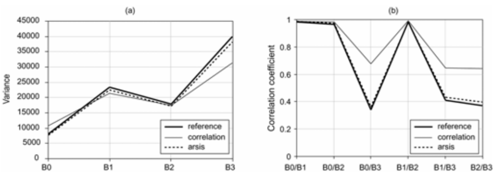

Figure 7. Comparison between actual and estimated spectral values

In Figure 7a, the variance comparisons highlight a large similarity between the original image and the ARSIS merged results for the four bands. The Correlation method overestimates B0 and underestimates B3 and more lightly B1. The Correlation method introduces too much information as the variance is overestimated in comparison to the original band. On the contrary, an underestimation corresponds to a loss of information. Only B2 is correctly modelled by both fusion algorithms.

The analysis of the correlation coefficients between each band (Figure 7b) shows a bad fused result for the band 3 obtained by the Correlation method. Finally, the ARSIS method produces better radiometric results than the Correlation method. Nevertheless, the Correlation method shows a good reproduction of information for B1 and B2, and a poorer especially for B3. These results confirm the visual and qualitative assessment of the two fusion algorithms.

6 CONCLUSIONS

The issue of Very High Resolution imagery products has been tackled in this paper. Table 1 clearly shows the limits and benefits of these products for urban studies. In order to improve the usefulness of these products in urban studies, the use of fusion algorithms has been evaluated. Various methods of fusion might be applied on very high satellite imagery products such as Quickbird images in order to provide useful and reliable products for urban studies. In this paper two of them, the UWT-M2 method based on the ARSIS concept and the Correlation method, were compared within the aim of providing useful information on urban areas.

Visual, qualitative and quantitative parameters have been evaluated in a protocol. This protocol combines global and local analysis for specific urban features, and allows the evaluation of the fused product for urban studies.

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