Fusion of SPOT5 multispectral and Ikonos panchromatic images

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ABSTRACT: The offer of high spectral and high spatial resolutions images has grown in the last decade. It is know possible to obtain data from different sources with different spatial and spectral resolutions. The field of data fusion of remotely sensed data grown also very fast in the last years. In this paper, an algorithm allowing the merging of SPOT 5 images and Ikonos images are proposed. This algorithm is based on the ARSIS concept and presents an implementation for a ratio of spatial resolution equal to 10. The ARSIS concept is first detailed. Then, the way of defining a new implementation based on this concept is presented, allowing to understand how to define new implementations and to develop new solutions based on this concept. The proposed algorithm is developed, describing the different steps for building a fused product from a SPOT 5 multispectral data at 10 m and from a IKONOS panchromatic data at 1 m. Some other methods are proposed. The evaluation of the quality of the different methods is achieved using a set of quantitative quality parameters. The visual quality of the products are evaluated by a set of interpreters. Conclusions are drawn on the quality of the proposed products.

1 INTRODUCTION

In the last decade the offer of optical high resolution images was growing. Different images with different spatial resolutions and different spectral bands are now available commercially. They exhibit usually either high spectral resolution and low spatial resolution, or low spectral resolution (broadband) and high spatial resolution. The high spatial resolution is necessary for an accurate description of shapes, features and structures. The different objects are better identified if high spectral resolution images are used.

The commercial companies are tackling the need for fusion products combining the high spatial and the high spectral resolutions using well-known procedures and deliver such products in an operational way. These fusion products are synthetic images aiming at simulating what a sensor having the same spectral bands but the highest spatial resolution would observe.

In this paper, the ARSIS concept is exposed. This concept is a general framework for defining implementations of image fusion algorithms. The complete description of the concept and of its implementation is presented. An example for the implementation of an algorithm for the fusion of Ikonos panchromatic and SPOT 5 multispectral images is proposed. This algorithm is experimented and compared on a dataset. In order to provide a good comparison of the results, it is compared through the protocol of Wald *et al.* (1997) to other methods proposed commercially. Some conclusions are drawn.

2 THE ARSIS CONCEPT

Let us denote the acquired images of lowest spatial resolution by B_l, and the images of highest spatial resolution by A_h. The subscripts l and h denote the spatial resolution of images B or A, i.e. low and high resolution, respectively. $B^{interp}{}_h$ denotes the result of the interpolation (resampling) of B_l from resolution l to h. Within each set, the images are geometrically aligned and have the same pixel sizes. Within the set of images B, B_{kl} denotes the image acquired in the spectral band k. The fusion methods aim at constructing synthetic images $B^*{}_h$, which are close to reality. The methods should perform a high-quality transformation of the multispectral content of B_l, when increasing the spatial resolution from l to h.

The general problem is the creation of a new set of images B^* from the original sets of images

$$B^* = f(A, B) \quad (1)$$

The general problem may be seen as the inference of the information that is missing in the images B_{kl} and the construction of the synthesized images $B^*{}_{kh}$. The ARSIS concept is based on the assumption that the missing information is linked to the high frequencies of the sets A and B. It searches a relationship between the high frequencies in the multispectral set B and the set A and models such a relationship. A method belonging to the ARSIS concept performs typically the following operations: (i) the extraction of a set of information from the set A, (ii) the inference of the information that is missing in the images B_{kl} using this extracted information and (iii) the construction of the synthesized images $B^*{}_{kh}$. The most recent methods perform a scale by scale description of the information content of both images and synthesis of the high-frequency information missing to transform the low spatial resolution images into high spatial resolution high spectral content images. Ranchin and Wald (2000) showed that many schemes can be accommodated within the ARSIS concept. Among them are the High-Pass Filtering (HPF) method (Chavez *et al.,* 1991), the method by Aiazzi *et al.* (1999) and three models presented in Ranchin and Wald (2000), making use of wavelet transform: Model 1, Model 2 and RWM, the latter being named after the initials of its authors (Ranchin, Wald, Mangolini, see Ranchin *et al.* (1994)).

The images of the sets A and B do not need to be commensurate. Some studies have been published where images acquired in thermal infrared bands have been synthesised with a better spatial resolution with a satisfactory quality by the means of images acquired in the visible range (Kishore Das *et al.,* 2001; Liu and Moore, 1998; Nishii *et al.*, 1996; Wald and Baleynaud, 1999).

It is difficult to sketch the general scheme for the application of the ARSIS concept. In the methods HPF and by Cornet *et al.* (2001), Diemer and Hill (2000), Liu and Moore (1998), Pradines (1986) or Price (1999), the modeling of the missing information from the image A to the image B is performed on moving windows of these images themselves. It is possible to focus more on the modelling of the missing high frequencies, expressed by Fourier coefficients or wavelet coefficients or other appropriate spatial transform.

Fig. 1 presents the general scheme that applies in the case of use of a multiscale model. This case is used in the following for a better description of the ARSIS concept. Similar schemes can be used in other cases, where other tools or strategies are used. The following sections detail several implementations of the ARSIS concept following the scheme in Fig. 1. Input to the fusion process are the images A at high spatial resolution (A_h, resolution n°1) and the spectral images B at low spatial resolution (B_{kl}, resolution n°2).

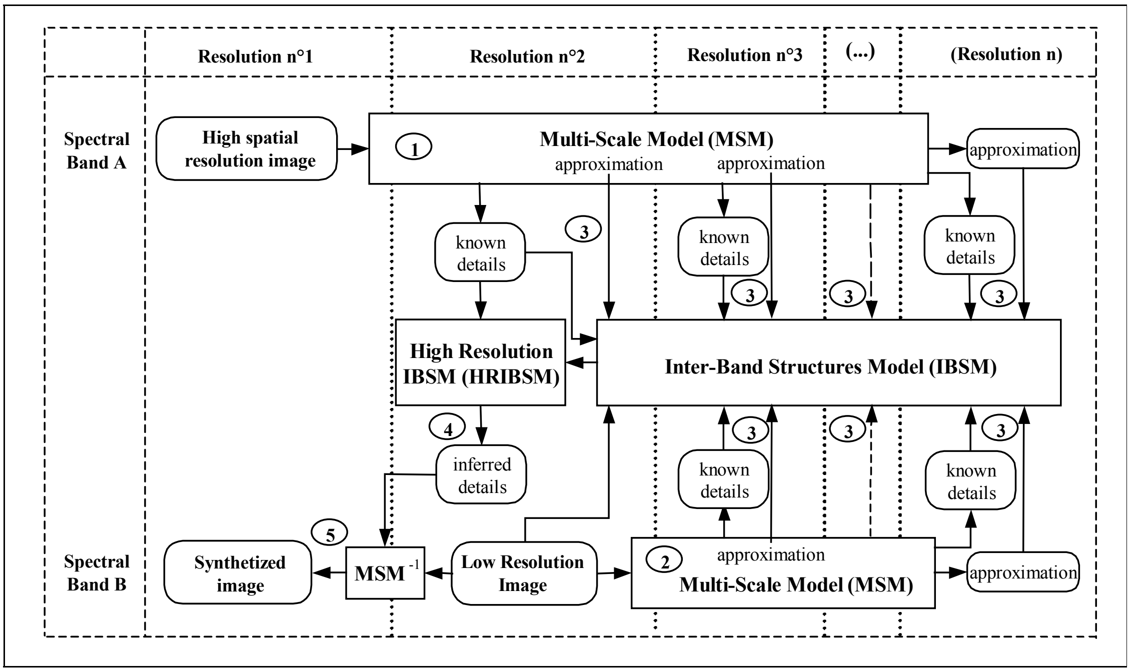

Fig. 1. General scheme for the application of the ARSIS concept using a multiscale model (MSM) and its inverse (MSM^{-1}). See text for further explanations.

Three models appear in this scheme. The Multiscale Model (MSM) performs a hierarchical description of the information content relative to spatial structures in an image. An example of such a model for remotely sensed images is the combination of the wavelet transform and multiresolution analysis (Ranchin, 1997). Ranchin and Wald (2000) provide details for the implementation of the algorithm of Mallat (1989) combined with a Daubechies wavelet. When applied to an image, the MSM provides one or more images of details, that is the high frequencies, and one image of approximation, that is the lower frequencies. As an example, assume an Ikonos image at 1 m resolution. The first iteration of the MSM gives one image of the structures comprised between, say, 1 and 2 m (details image) and one image of the structures larger than 2 m (approximation image). The spatial variability within an image can thus be modelled and the model can be inverted (MSM^{-1}) to perform a synthesis of the high-frequency information.

The Inter-Band Structure Model (IBSM) deals with the transformation of spatial structures with changes in spectral bands. It models the relationships between the details or approximation observed in the image *A* and those observed in the image *B*. The IBSM may relate approximations and/or details for one or more resolutions and one or more spectral bands. As an example, the Model 2 described by Ranchin and Wald (2000) relates the details observed at resolution n°3 in the image *A* and the image B_k by means of a linear relationship.

The High Resolution Inter-Band Structure Model (HRIBSM) performs the transformation of the IBSM with the change in resolution. This operation is not obvious. Many works have demonstrated the influence of the spatial resolution on the quantification of parameters extracted from satellite imagery (Lillesand and Kiefer, 1994; Woodcock and Strahler, 1987). To our knowledge, no published fusion method paid particular attention to this point and the HRIBSM is often set identical to the IBSM. Ranchin *et al.* (1994) performed a multiscale synthesis of the parameters of their IBSM from resolution n°3 to resolution n°2.

The operations are performed as follows. First, the MSM is used to compute the details and the approximations of image *A* (Step 1 in Fig. 1). The same operation is applied to image *B* (Step 2). The analysis is performed for several resolutions, up to *n* in Fig. 1 - that is (*n-1*) iterations for the analysis of the image *A* and (*n-2*) iterations for that of B_{kl}. These analyses provide one approximation image and several images of details for *A* and *B*. The known details at each resolution are used to adjust the parameters of the IBSM (Step 3). From this model is derived the HRIBSM (at resolution n°2 in this figure), which converts the known details of image *A* into the inferred details of image B_k (inferred details, Step 4). Finally, MSM^{-1} from resolution n°2 to resolution n°1 performs the synthesis of the image B^*_{kh} (Step 5).

3 IMPLEMENTATION OF THE ARSIS CONCEPT

3.1 *The MSM Model*

The most used MSM model for implementing the ARSIS concept is the multiresolution analysis combined with wavelet transform. A group of authors (Ranchin and Wald, 2000; Garguet-Duport *et al.*, 1996, Yocky, 1996) uses the algorithm proposed by Mallat (1989). Others (Nunez *et al.*, 1999; Ranchin *et al.*, 2003) use that proposed by Dutilleux (1989), called here undecimated wavelet transform (UWT).

Other tools exist for this MSM model. Laplacian pyramids (Burt and Adelson, 1983) can be used for the hierarchical description of information as well as gaussian pyramids (Tom, 1987). Chavez *et al.* (1991) defined filters for the High Pass Filtering (HPF) method. Blanc *et al.* (1998) used iterative filters banks in place of wavelet transform. Ranchin *et al.* (2003), Aiazzi *et al.* (2002), propose the use of generalized laplacian pyramids (GLP). Other solutions exist such as morphological pyramids (Laporterie, 2002) or Fourier transformations.

3.2 *The IBSM Model*

Numerous solutions exist for the Inter-Band Structure Model (IBSM). Ranchin and Wald (2000) proposed two global models of transformation called model 1 and model 2, both performing on the detail images. Model 1 (M1) is an identity model. The missing details in image B are identified to those known in image A. Model 2 (M2) adjusts the mean and variance of the two probability density functions (pdf) of the structure images of A and B at resolution n°3.

Ranchin *et al.* (2003) describe two local IBSM models. The first one (RWM), used in this paper, describes the local transformation between the structure descriptions of A and B given by the MSM model at resolution n° 3 (Figure 1). The second one (AABP) is used similarly, but applies on approximations given by the MSM model.

3.3 *The HRIBSM Model*

The choice of the High Resolution Inter-Band Structure Model (HRIBSM) is not obvious. Influence of the spatial resolution on the set of information extracted from satellite imagery is well known but not well modeled. To our knowledge, no published fusion method paid particular attention to this point and the HRIBSM is often set identical to the IBSM, except Ranchin *et al.* (1994) who performed a multiscale synthesis of the parameters of their IBSM from resolution n°3 to resolution n°2.

4 PROPOSED IMPLEMENTATION FOR THE FUSION OF IKONOS PAN AND SPOT 5 MULTISPECTRAL IMAGES

One implementation of the ARSIS concept is a selection of a MSM, an IBSM and a HRIBSM model. In the case of the fusion of Ikonos panchromatic image with SPOT 5 multispectral images, the ratio between the two resolutions is 10. Hence, the MSM model should handle it. The MSM used is based on the UWT algorithm proposed by Dutilleux (1989). It was adapted to handle the ratio of 10 through a combination of two ratio: 5 and 2. The filters used were the polynomial filters proposed by Aiazzi *et al.* (2002). Then, the choice of the IBSM is in the case proposed the M1,M2 and M3 models proposed by Ranchin and Wald (2000). Finally the HRIBSM is chosen as the identity model.

In order to compare results to other methods, the Brovey, the multiplicative and PCA methods provided in the commercial software ERDAS©, and the IHS method were applied to the set of images and some results are presented in the next paragraph.

5 EXAMPLE AND RESULTS

The Ikonos panchromatic image and the SPOT 5 multispectral image were acquired on the 21th of July 2003 over Madrid. Following the protocol defined by Wald *et al.* (1997) the Ikonos panchromatic image was resampled at 10 m and the multispectral SPOT 5 image resampled at 100 m. From this set of data, the resampled SPOT 5 are fused with the resampled Ikonos image. Then the fused products can be compared in a pixel basis with the original SPOT 5 multispectral images.

Table 1 presents a set of statistical results for the different methods for the SWIR band of SPOT 5.

	IHS	PCA	Brovey	Multiplicative model	ARSIS Model 1	ARSIS Model 2	ARSIS Model 3
Bias (ideal value: 0) relative to the mean original value	-44 -49 %	41 45 %	10 11 %	-21363 -23367 %	0.0 0.0 %	0.0 0.0 %	0.0 0.0 %
Actual variance-estimate (ideal value: 0) relative to the actual variance	-1039 -131 %	502 63 %	-24 -3 %	$-9.2\ 10^{+7}$ $-1.1\ 10^{+7}$	-2002 -251 %	149 19 %	325 41 %
Correlation coeff. between original and estimate (ideal value: 1)	0.693	0.737	0.795	0.785	0.578	0.803	0.815
Standard-deviation of the differences (ideal value: 0) rel. to the mean of original value	31 34 %	19 21 %	18 20 %	9614 10516 %	43 47 %	17 19 %	16 18 %

Table 1. Some statistics on the differences between the original and synthesized images, for SWIR band.

Table 1 reports some statistics on the relative discrepancies between the original image in the SWIR band and the image synthesized for the seven methods selected. The differences are computed on a pixel basis and one image of differences. 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 synthesized 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. The ideal value for these parameters is 0. In addition, the difference between the variance of the original image and that of synthesized 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 Bkl and B*kl is also computed. The ideal value is 1.

The analysis of this table allows to classify the methods from the radiometric point of view. The best methods are achieved through implementation of the ARSIS concept. The choice of the IBSM model influences strongly the results. The best solution for all the statistical parameters presented in Table 1 is the ARSIS M2 implementation.

A qualitative evaluation was also performed by experienced interpreters. Firstly they evaluate the fused products compared to the original one at the spatial resolution of 10 m and secondly the fused products at the resolution of the panchromatic image at 1 m. The methods were then ranked by the analysts. In each case, two points of view were selected for ranking: the quality of the details produced by the fused methods, i.e., how much objects can be detected and identified by their shapes and their sizes and how much these sizes are similar to the actual sizes, and the quality of the radiometry perception achievable through the fused products, i.e., how much the actual grey levels and colours are reproduced and how much objects can be detected and identified by their colours.

Table 2 presents the results of these two rankings:

Details	ARSIS-M1	IHS	Brovey	PCA	ARSIS-M2	ARSIS-M3	Multiplicative model
Radiometry	ARSIS-M2	ARSIS-M3	PCA	ARSIS-M1	IHS	Brovey	Multiplicative model

Table 2. Ranking of the seven methods by analysts.

6 CONCLUSION

In this paper the ARSIS concept was presented. In order to prove its flexibility and the quality of the framework proposed, a fusion between an Ikonos panchromatic image and a SPOT 5 multispectral image was studied. The implementation of the ARSIS concept was expressed and an example provided. The resulting fused products were evaluated through the protocol proposed by Wald *et al.* (1997) and compared with other commercial fusion methods. The statistical evaluation enhanced the quality of the results provided by the implementation of the ARSIS concept. An ongoing work will try to propose a global solution to fuse images with any ratio of resolution.

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