Sensor fusion to improve the spatial resolution of images: the ARSIS method

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Sensor fusion to improve the spatial resolution of images: The ARSIS method

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ABSTRACT: Since the beginning of remote sensing, the spatial resolution of images has always increased. As a general tendency, the geometrical resolution is always privileged with regard to radiometric resolution. The future trends in Earth Observation will follow the same logic. However, in a lot of applications, it is necessary to combine high spatial and high spectral resolution. The ARSIS method was designed to reach this requirement and synthesises high spectral resolution images with the best available spatial resolution in a set of images. After a presentation of the method itself, two examples of sensor fusion of images are provided. Some potentialities of the use of such synthesised images will be evoked.

1 INTRODUCTION

Since the begin of remote sensing, the spatial resolution of images had always increased. From Landsat MSS (80 m in multispectral bands) to SPOT HRV (20 m in XS multispectral bands and 10 m in P panchromatic band), IRS-1C (23.5 m in multispectral bands and 5.8 m in panchromatic band) and even to the Russian sensor KVR-1000 (2 m in panchromatic band), the trend was to obtain a better spatial resolution in order to have an accurate description of the Earth phenomena. The geometrical description is always privileged. The radiometric description always suffers from a lack of spatial resolution.

The future trends in Earth observation will follow the same logic: one will obtain a good geometrical description or a good radiometric description but with a lower spatial resolution. Future satellites will have a spatial resolution from 1 to 3 m in panchromatic band and between 4 and 15 m in the multispectral band.

However, in a lot of applications, it is necessary to have a high spectral resolution combined with a high spatial resolution. To reach this requirement, sensor fusion provides solutions. Many methods which allow the improvement of the spatial resolution of images exist. But the majority of them do not respect the spectral content of the original multispectral images.

To fulfil this objective, *i.e.* the improvement of the spatial resolution of multispectral images up to the best available spatial resolution in the set of images with respect to the original content, the ARSIS method (from its French name "amélioration de la résolution spatiale par injection de structures") was designed. In the case of the SPOT imagery, this method was demonstrated has given the best achievable results in terms of preservation of the original spectral content of images (Mangolini *et al.*, 1995).

After presentation of the ARSIS method, two examples of sensor fusion of images will be provided: the case of the merging of the SPOT XS images (20 m) and of the SPOT P image (10 m) and the improvement of the spatial resolution of the SPOT XS images up to the spatial resolution of the KVR-1000 one (2 m).

The ARSIS method is a general solution to sensor fusion. It has been applied to various cases. The improvement brought by this method was demonstrated in applications like the computation of NDVI or urban mapping. The demonstration of the potentialities of such a method will lead to its use with images provided by new sensors and in new applications.

2 ARSIS METHOD

The ARSIS method is based on the use of the wavelet transform and the multiresolution analysis. The multiresolution analysis allows the computation, from an original image, of coarser and coarser approximations. In this scheme, the wavelet transform allows to represents the difference of information between two successive approximations. These tools are often represented using a pyramidal scheme as proposed Figure 1.

A more complete presentation of these tools in the field of remote sensing can be found in Ranchin (1997).

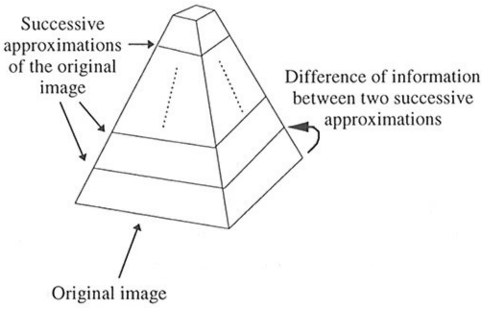

Figure 1. Representation of the successive approximations of an image by the means of a multiresolution algorithm

For all the merging processes, some pre-requisites are needed:

- images shall have different spatial and spectral resolutions,
- images to merge shall represent the same area,
- images shall be accurately registered,
- no major change shall occurred on the area during the interval between time acquisition of the source images.

If the last requirement is not satisfied, the aim of the merging process can be the updating of the observed area (Ranchin, Wald, 1996a). These requirements are not limiting the merging process to images acquired by the same platform. The process can also apply to the merging of images acquired by airborne and spaceborne sensors. Many methods have been proposed to enhance the spatial resolution of images taking advantages of the presence of one or more images with a better spatial resolution (see for example Carper *et al.,* 1990; Chavez *et al.,* 1991). But, if one of the objectives is to bring each image at the best spatial resolution available, while retaining all the spectral content of the image to enhance, only a few of them satisfy it. A comparison of the most representative merging processes has been achieved by Mangolini *et al.* (1995).

In order to fulfil this objective, the ARSIS method was first designed for the SPOT imagery and then generalised to the merging of images with different spatial and spectral resolutions. This method uses the wavelet transform and the multiresolution analysis to decompose the two images to be merged as in Figure 2.

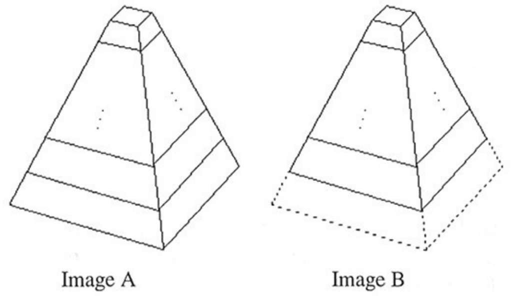

Figure 2. The use of the multiresolution analysis in the ARSIS method.

A multiresolution analysis using the wavelet transform is applied to image A and image B, describing image A and image B at different spatial resolutions and the differences of information between the successive approximations of image A and image B. The wavelet coefficients provided by the multiresolution analysis of the high spatial resolution image A, between the scale of image A and the scale of image B, describe the missing information for the synthesis of the image B at the same spatial resolution than the one of image A.

The simplest solution is to shift the wavelet coefficients from pyramid A to pyramid B and to use them to synthesise image B at the spatial resolution of image A. If the wavelet coefficients provided by image A are used without modifications, the synthesised image B will not be equivalent to "what would be seen by sensor B if it had the spatial resolution of sensor A". Hence, to improve the quality of the synthesised image, the model, to transform the wavelet coefficients provided by the multiresolution analysis of image A in the wavelet coefficients needed for the synthesis should take into account the physics of the environment.

Whatever this model is, the ARSIS method preserves the spectral content of original image because of its very definition. A multiresolution analysis applied to the synthesised image B will allow the computation of an approximation similar to original image B.

As an example, Figure 3 presents the application of the ARSIS method to the case of the SPOT imagery.

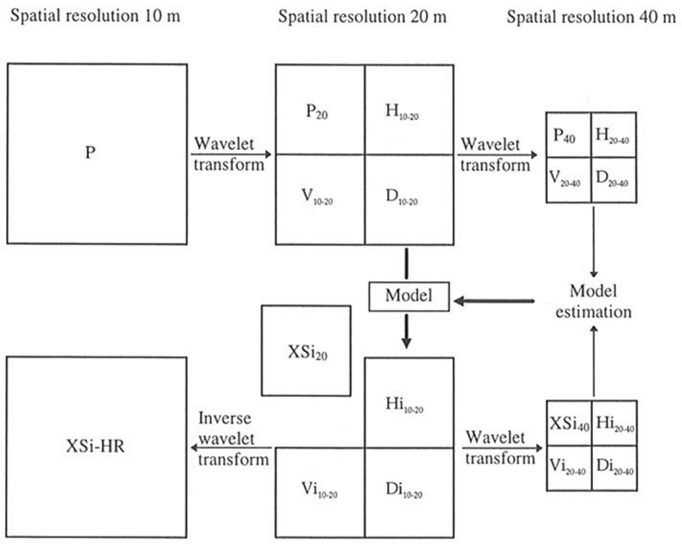

Figure 3. Application of the ARSIS method to the SPOT imagery

The set of images is composed in this case of a panchromatic image at the spatial resolution of 10 m and three multispectral images XS1, XS2, XS3 at the spatial resolution of 20 m. The aim of the ARSIS method is to compute the three XSi images at the spatial resolution of 10 m and to preserve the original spectral content. Two iterations of the multiresolution analysis using the wavelet transform are applied to the original panchromatic (P) image and one iteration to the original XSi image. The mother wavelet used is the one proposed by Daubechies (Daubechies, 1988). It is an orthogonal wavelet allowing the decorrelation of the structures between the different approximations and is implemented through a four coefficients filter. A model of transformation, for each direction, from the panchromatic wavelet coefficient images to the XSi wavelet coefficient images is estimated at the spatial resolution of 40 m. This model can be of various types. The simplest one is the identity model. A convenient one can be an adjustment of the mean and the variance of the histogram of the wavelet coefficient images. The model must take into account the physics of both images and the correlation and anti-correlation between both images. Several models have been tested by Mangolini *et al.* (1992). The best results were achieved with a model taking into account the local variation between the P and the XSi wavelet coefficient images. The estimated model is then inferred at the spatial resolution of 20 m. Then, it is applied to the transformation of the wavelet coefficient images representing the information between 10 and 20 m of the P image, into those corresponding to the XSi image. Then, the multiresolution analysis is inverted and the XSi image at the spatial resolution of 10 m, called XSi-HR, is synthesised from the original XSi image and from the wavelet coefficient images computed through the model.

Figure 4 presents the general scheme of the ARSIS method. First a multiresolution analysis using the wavelet transform is used to compute the wavelet coefficients and the approximations of image A (1). The same operation is applied to the image B (2). The wavelet coefficients provided by each decomposition are used to compute a model of transformation of the known wavelet coefficients of image A into the known wavelet coefficients of image B. This model takes into account the physics of both images and the correlation or anti-correlation existing between both wavelet coefficients images (3). The model can have various forms and take into account more than one scale. This model is then used to compute the missing wavelet coefficients (4). The inversion of the multiresolution analysis (WT^{-1}) allows the synthesis of the image B with the spatial resolution of image A (5).

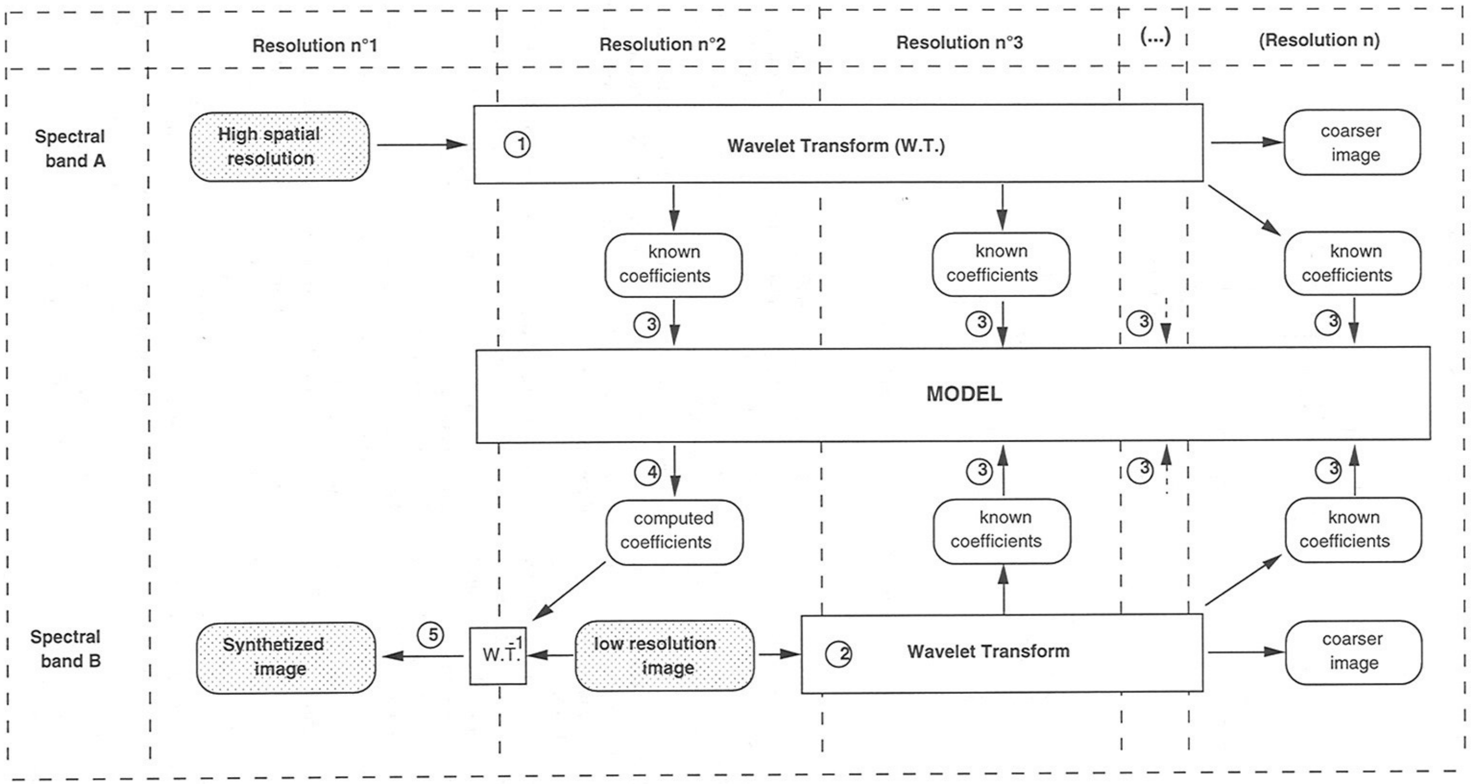

Figure 4. General scheme of the ARSIS method.

Mangolini *et al.* (1995) and Wald *et al.* (1997) proposed a method to evaluate quantitatively the different sensor fusion techniques. ARSIS was shown to give the best results in terms of preservation of the spectral quality.

In the next section two examples of the application of the ARSIS method are proposed.

3 EXAMPLES

3.1 *Fusion of SPOT-HRV P and XS images*

The first example deals with the SPOT imagery. The SPOT HRV sensor delivers one panchromatic P image with a spatial resolution of 10 m (spectral range: 0.51 - 0.73 μm), and three multispectral XS images with a spatial resolution of 20 m (spectral ranges: 0.5-0.59 μm, 0.61-0.68 μm, 0.79-0.89 μm). The images were acquired simultaneously and are superimposable after registration. The set of images was acquired on September 11, 1990 over Barcelona (Spain). Barcelona is a large city located in the north-east of Spain, on the Mediterranean seashore. The complete area presents a harbour, an airport, urban areas with roads and motorways, rivers, agricultural lots, montaneous areas and a Mediterranean vegetation. Figure 5a presents an extract of the XS1 image of the area of Barcelona (Spain). This extract contains agricultural lots mixed with urban area. The roads and the motorways are clearly visible, though, the interchanges on the motorways are difficult to distinguish.

~500 m

Figure 5a. Original XS1 image (20 m). Copyright CNES-SPOT Image (1990).

~500 m

Figure 5b. Synthesised XS1-HR image (10 m).

The ARSIS method allows to synthesise the multispectral images (image B) with the spatial resolution of the panchromatic image (image A), i.e. 10 m. The resulting images are called XSi-HR. The XS1-HR image is presented in Figure 5b.

The original XS1 image was interpolated with a nearest-neighbour algorithm. The visual quality of the XS1-HR image is due to the injection of the information extracted from the panchromatic image and modelled in order to preserve its spectral properties. On the XS1-HR image, one can clearly distinguish the interchanges on the motorways, the road network in the upper left corner of the image and the large buildings.

3.2 *Fusion of KVR-1000 and SPOT-HRV XS images*

In the second example, the set of images is composed of a SPOT XS scene of the town of Riyadh (Saudi Arabia) acquired on May 16, 1993 and a Russian image KVR-1000 of the same area acquired on September 7, 1992. The three multispectral images (image B) have a spatial resolution of 20 m and the KVR-1000 image (image A) has a spatial resolution of 2 m and a spectral range of 0.51 to 0.71 mm. Figure 6a presents a composition of the original XS images.

The ARSIS method allows the computation of XS images at the spatial resolution of 2 m. Figure 7b shows a composition of these synthesised images. In this case, the gap between the spatial resolution of image A and of image B is important. This area is composed of a large interchange of two urban motorways, a lot of buildings and some sandy areas. The large object at the right side of the motorway, in the lower part of the Figure 6b, is a mall. Due to the small details which appear in the synthesised image it is possible to distinguish the structures of this mall, and all the buildings in this area. The preservation of the spectral content of XS images, allows the application of a classifier, automatic or not, in order to extract the roads and the buildings.

Hence, they can be used for classification, or for other methods that need to use the multispectral content provided by the whole set of images with the best spatial resolution available. Ranchin and Wald (1995) have shown the improvement brought by the use of the ARSIS method, to extract roads in urban areas by the means of classification methods.

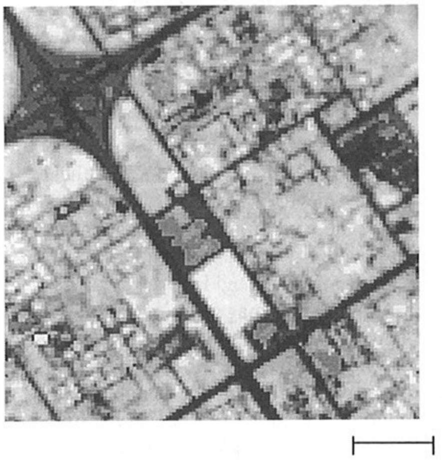

Figure 6a. Composition of the original XS images. Copyright CNES-SPOT Image (1993).

Figure 6b. Composition of the synthesised XS images (2 m).

4 CONCLUSION

The ARSIS method is a new method for sensor fusion, based on the multiresolution analysis and the wavelet transform. By construction, ARSIS ensures the preservation of the spectral content of original images when improving their spatial resolution. The synthesised images can be therefore used for other purposes than visual interpretation. In the case of the SPOT imagery, it was demonstrated that the accuracy and the quality of the road network extracted was increased by the use of images synthesised by the ARSIS method (Ranchin, Wald, 1995).

The ARSIS method was successfully applied to the merging of the SPOT XSi and P images (Ranchin *et al.,* 1994), to the merging of Landsat Thematic Mapper band 6 (120 m) with the other bands of the Thematic Mapper instrument (30 m) (Ranchin, 1993), to the merging of the Landsat Thematic Mapper bands (30 m) with the SPOT P image (10 m) (Blanc *et al.,* 1996) and to the merging of the SPOT XSi images with the image from the Russian panchromatic sensor KVR-1000 (2 m) (Ranchin *et al.,* 1996a).

It was also demonstrated that this method can be applied for the SPOT 4 (Ranchin, Wald, 1996b) and the SPOT 5 (Ranchin *et al.,* 1996b; Couloigner *et al.* 1997) missions. The ARSIS method will be used in the near future to improve the accuracy of the results of the image processing techniques usually applied to the multispectral set of data in order to extract information.

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