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USING ITERATED RATIONAL FILTER BANKS WITHIN THE ARSIS METHOD FOR PRODUCING 10 M LANDSAT MULTISPECTRAL IMAGES.

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ABSTRACT:

The ARSIS concept makes use of wavelet transforms and multiresolution analysis to improve the spatial resolutions of images from a set made of a low resolution image in the same spectral band and a high resolution image in an other spectral band. The paper deals with the use of rational filter banks in ARSIS. Indeed, first this concept was operationally applied with dyadic wavelet transforms that limit the merging of images with a ratio between spatial resolutions equals to a power of two. Provided some conditions, rational filter banks can be seen as a good approximation of rational wavelet transforms and, thus, enable a more general merging of images with ARSIS. The advantages of those rational filter banks compared to other methods are discussed and illustrated by an example of fusion of a 10 m SPOT Panchromatic image and a 30 m Landsat Thematic Mapper (TM) multispectral image into a synthetic 10 m multispectral image called hereafter TM-HR.

1. INTRODUCTION

The ARSIS concept from its French acronym "Amélioration de la Résolution Spatiale par Injection de Structures", enables the fusion of images having different spatial and spectral resolutions. More precisely, it is meant to synthesize a high spatial resolution image by merging a low resolution image in the same spectral band and a high resolution image in an other spectral band, thanks to wavelet transforms and multiresolution analysis. In other words, the aim of ARSIS is to increase the spatial resolution of a multispectral image without modification of its spectral content by using the structures extracted from a higher resolution image provided a sufficient level of local spatial correlation between the images. For more information about ARSIS, see Ranchin *et al.* (1993).

In the past, the ARSIS concept was operationally applied with dyadic wavelet transforms that limit the merging of images with a resolution ratio equals to a power of two.

We present an extension of the use of ARSIS by using rational filter banks as non dyadic rational wavelet transforms.

First a short overview is made on rational filter banks and their link with rational wavelet transforms. Then, to assess the efficiency of those filter banks applied in ARSIS, we present an example of merging of a 10 m SPOT Panchromatic image and a 30 m Landsat TM multispectral image to synthesize a 10 m multispectral TM-HR image. Two approaches were conducted which both used a 2/3 filter bank in ARSIS to synthesize the 10 m multispectral TM-HR image. Then these two methods were compared to other methods that made use of a bicubic interpolation with resampling rate 2/3 and 3/2.

Our study is illustrated by an extract of a Landsat TM multispectral image and SPOT Panchromatic image of the region of Berre l’Etang close to Marseille in the southeast of France (Figure 1)

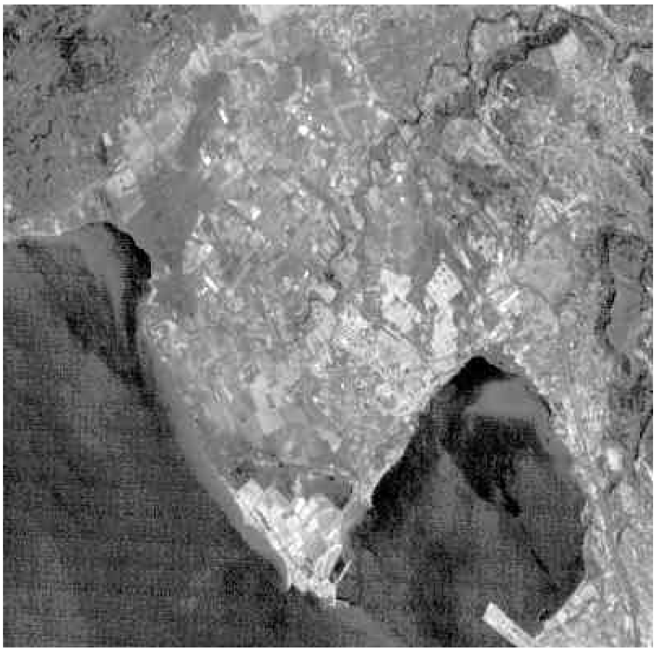


Figure 1. Original Landsat TM 1 (region of Berre l'Etang close to Marseille).

2. RATIONAL FILTER BANKS AND DISCRETE RATIONAL WAVELET TRANSFORMS

The purpose of this section is to present a short overview of the rational filter banks structure and their link with discrete wavelet transforms. Blu (1993 a) showed that, under some conditions, two-band iterated filter banks with rational rate change p/q can be used to approximate very closely samples of discrete wavelet transform with the same rational dilation factor. More precisely, the structure of rational filter banks is similar to the dyadic filter banks one which provides wavelet analysis of the input signal: this general structure is shown Figure 2. Those filter banks are composed of an iterated low-pass branch and a high-pass branch between two consecutive low-pass branches. The description of the design procedure of the rational lossless finite impulse response (F.I.R.) low-pass and high-pass filters is given in Blu (1993 b).

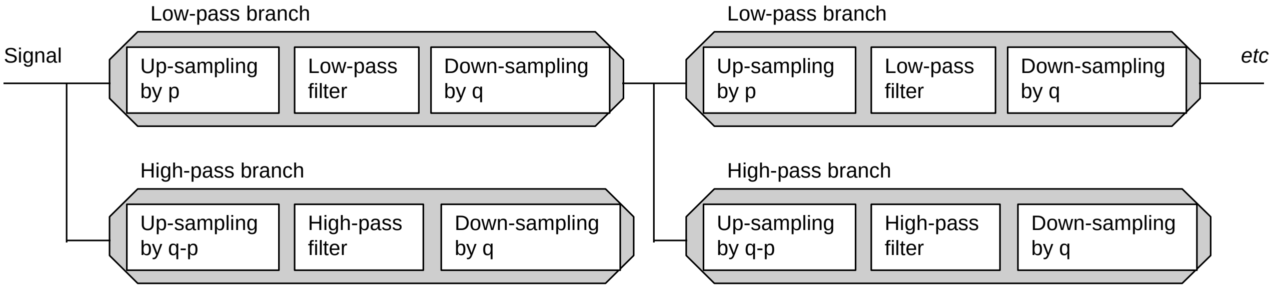


Figure 2. General scheme of iterated rational filter banks.

The dyadic case is obtained with p=1 and q=2. In this case, the high-pass branch outputs are samples of discrete dyadic wavelet transform. In the rational case, this is no longer true. It still could be seen as a kind of multiresolution analysis but the decomposition of the signal is not plainly made on dilated and shifted versions of a single function (the wavelet). Nevertheless, when p=q-1, Blu (1993-a) proved that the difference between the high-pass outputs and the samples of a corresponding rational discrete wavelet transform can be reduced by suitable parameters in the filters design, so that the iterated rational filter bank can generate a good approximation of a wavelet transform.

As a conclusion, we presently have an approximation of a discrete wavelet transform with a rational dilation factor (q-1)/q at our disposal. The extension of the use of those iterated rational filter banks to images is easily done following Mallat (1989). We have to notice that the suitable parameters for the filters design increase the number of coefficients of the filters and, therefore, are usually "longer" than in the dyadic case. For example, the low-pass filter and the high-pass filter selected here to be applied in ARSIS method have impulsional responses comprising respectively 21 and 11 coefficients.

2.1 PRODUCING 10 M LANDSAT TM MULTISPECTRAL IMAGE

3. THE ISSUE

Our aim is to synthesize a 10 m multispectral TM-HR image from the merging of a 10 m SPOT Panchromatic image and a 30 m Landsat TM multispectral image of the same geographical area. Both images are superimposable. The ratio of their resolution is 1/3. It is the reason why ARSIS with dyadic wavelet transform can not be strictly applied in this case. Moreover, we assume, for the synthesis of a filter bank with a rational rate change p/q, that p=q-1. Therefore, two ways exist to synthesize the TM-HR multispectral image with ARSIS.

3.1.1 ARSIS WITH A 2/3 FILTER BANK

The first way consists in using ARSIS with a 2/3 filter bank. There are two possibilities:

- *ARSIS #1:* the 30 m Landsat TM image is enhanced to 20 m by the use of ARSIS with a 2/3 filter bank and the SPOT Panchromatic resampled at the resolution 20 m. Then the 10 m TM-HR image is synthesized from the 10 m SPOT Panchromatic and the synthesized 20 m Landsat TM image using ARSIS with a dyadic wavelet transform.

- *ARSIS #2:* the 30 m Landsat TM image is enhanced to 15 m by the use of ARSIS with a dyadic wavelet transform and the SPOT Panchromatic resampled at the resolution 15 m Then the 10 m TM-HR image is synthesized from the 10 m SPOT Panchromatic and the synthesized 15 m Landsat TM image using ARSIS with a 2/3 filter bank.

The method *ARSIS #2* is illustrated in Figure 3. Note that the 15 m SPOT Panchromatic image is generated with the 2/3 filter bank but it could have been done by a bicubic interpolation with a resampling rate 2/3.

3.1.2 ARSIS WITHOUT A 2/3 FILTER BANK

This way consists in using a bicubic interpolation in order to circumvent the fact that the ratio of resolutions (*i.e.* 10 m and 30 m) is not a power of two. There are also two possibilities:

- *ARSIS #3:* the 30 m Landsat TM image is enhanced to 20 m by the use of a bicubic interpolation with resampling rate 2/3. Then the 10 m TM-HR image is synthesized from the 10 m SPOT Panchromatic and the synthesized 20 m Landsat TM image through ARSIS with a dyadic wavelet transform.

- *ARSIS #4:* the 30 m Landsat TM image is resampled using a bicubic interpolation with a resampling rate of 2 to generate a 40 m Landsat TM image. Then ARSIS with a dyadic wavelet transform is applied two times to synthesize the 10 m TM-HR.

In both approaches, a bicubic interpolation is used: the Landsat TM images are changed into new images having a pseudo spatial resolution of either 20 m (*ARSIS #3*) or 40 m (*ARSIS #4*). As a consequence, the merging between SPOT and Landsat is not as complete as *ARSIS #1* or *ARSIS #2* because there is no injection of structures from the SPOT image between 30 m and 20 m in the case of *ARSIS #3* and a degradation of the Landsat TM image resolution before the merging in the case of *ARSIS #4.*

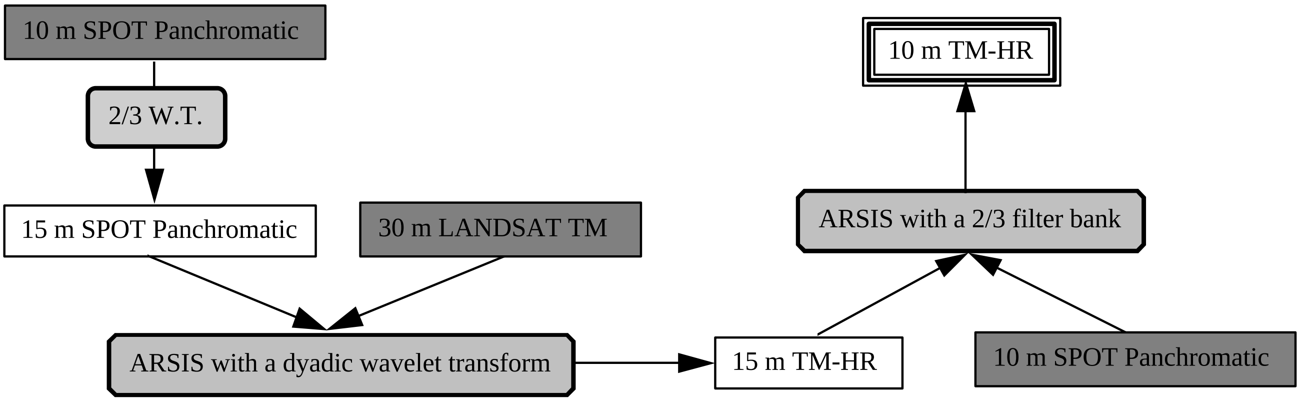


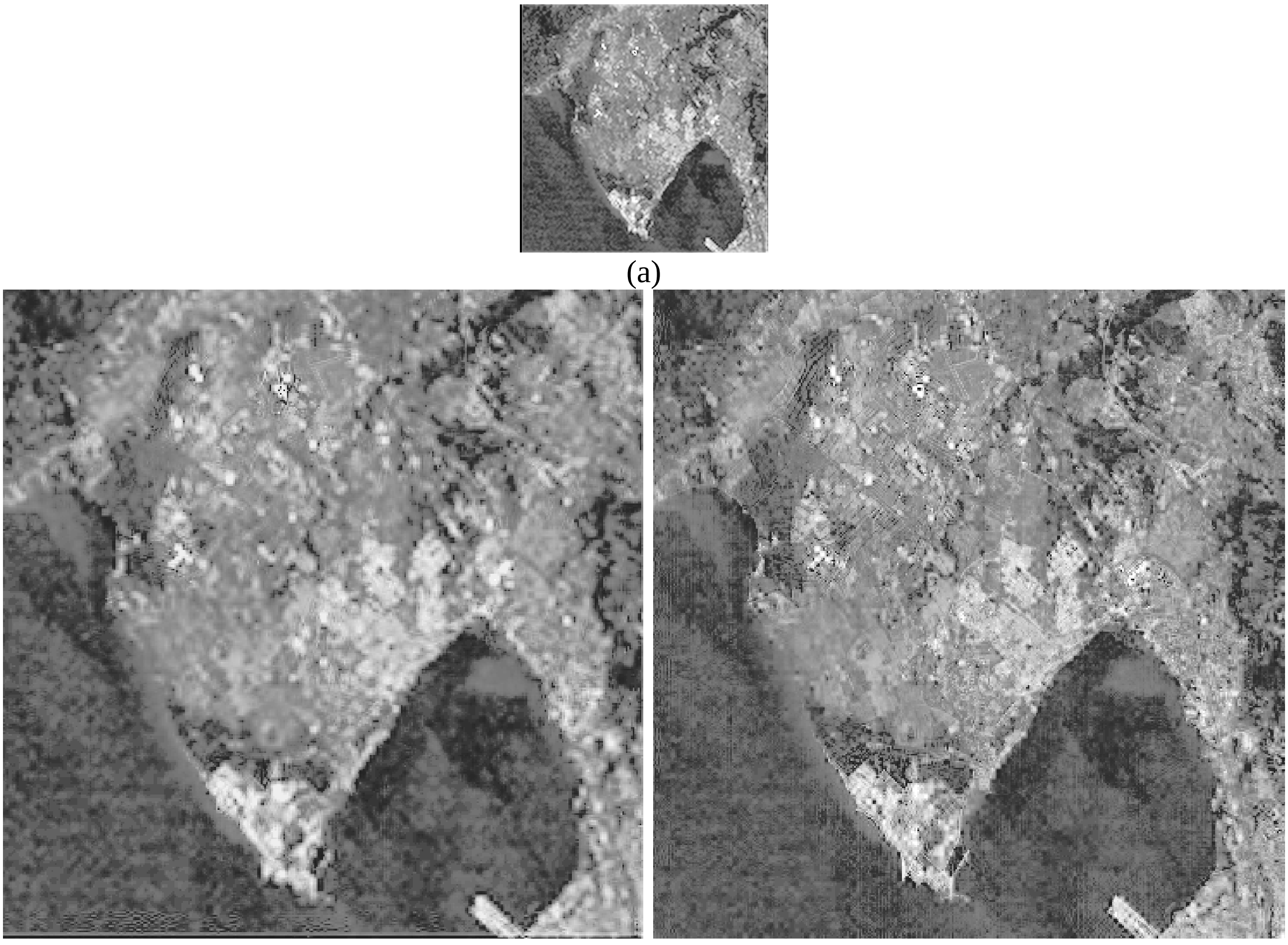
Figure 3. Illustration of the different stages of the method ARSIS #2

3.2 QUALITY ASSESSMENT OF THE SYNTHESIZED IMAGES

These different approaches generate four sets of synthetic enhanced multispectral images. The quality of these sets is assessed by the mean of the approach described in Mangolini *et al.* (1995). Indeed, the following approach was used to quantify the quality of the merging of the SPOT Panchromatic image and the Landsat TM multispectral image. The SPOT and the Landsat images were interpolated to a lower resolution of respectively 30 and 90 m by using bicubic interpolation. Then, the four methods were applied to synthesize Landsat TM multispectral images at 30 m called hereafter TM_1^*, ..., TM_4^*. Those images are compared visually and on a pixel basis to the original TM images. Only the methods *ARSIS #2* and *ARSIS #3* are presented here for discussion. The two other methods are worse as far as visual and quantitative assessment are concerned.

3.2.1 VISUAL ASSESSMENT

The quality of the synthesized images can be analyzed by a simple visual inspection. For example, the visual inspection is based on the comparison between the original 30 m TM-1 (band 1) in the Figure 1 and the synthesized 30 m TM_3^*-1 and TM_2^*-1 images (resp. (b) and (c) of the Figure 4). The TM_2^*-1 image is obviously less blurred than the TM_3^*-1 one. See, for example, the limits of the fields in the cape in the lower part of images (b) and (c) of Figure 4. In other words, *ARSIS #2* method provides a better enhancement of the resolution than the *ARSIS #3* method. However, despite a better spatial resolution, the TM_2^*-1 image presents several artifacts that look like sort of waves near radiometric discontinuities in the image. Those vibrations are due to Gibbs effects and are all the more important and visible as the filters used for the decomposition have a great number of coefficients. It is the reason why ARSIS with the 2/3 filter bank generate more artifacts near discontinuities than the methods using only dyadic transforms (*ARSIS #3* and *ARSIS #4*). These vibrations are clearly visible in the upper left part of images (b) and (c) of Figure 4.


(a)

(b) (c)

Figure 4. (a) 90 m resampled Landsat TM-1. (b) 30 m Landsat TM_3^* 1 with *ARSIS #3*. (c) 30 m Landsat TM_2^*-1 with *ARSIS #2*.

3.2.2 QUANTITATIVE ASSESSMENT

Quantitative assessments are based upon usual criteria for comparison (bias, correlation coefficient, variance, *etc.*) computed in several sub-regions of the multispectral Landsat TM images (the original TM and the synthesized TM^*).

This study confirms the visual inspection: basically *ARSIS #2* method provides better results than the *ARSIS #3* method. But, in the regions with strong radiometric discontinuities, *ARSIS #2* approach generates artifacts that locally decrease the quality of the synthesized image.

Moreover, generally, we notice that the ARSIS merging is all the more efficient as there is locally a sufficient level of local spatial correlation between the images.

4. CONCLUSION

As a conclusion, rational filter banks can be useful for ARSIS assuming a certain regularity of the images to merge. More precisely, the *ARSIS #2* method using the 2/3 filter bank provides better results as far as visual quality of the resolution and criteria used for comparison (bias, correlation coefficient, variance, *etc.*) are concerned assuming that the images to merge do not have large discontinuities. However, discontinuities in images introduce artifacts that decrease the quality of the fusion.

Moreover, the quality of the ARSIS merging of Landsat TM multispectral with SPOT Panchromatic is less satisfactory than the ARSIS merging of a 20 m SPOT XS multispectral image with a 10 m SPOT Panchromatic image. This can be partially explained by the fact that the resolution gap "to fill in" is more important in the first case than in the second one.

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