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Fusion of multispectral and panchromatic images using new methods based on wavelet transforms – Evaluation of crop classification accuracy

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ABSTRACT: One of the aims of our research team is to develop algorithms to assign automatically a crop to a cadastral parcel, matching raster information (multispectral classified images) and vectorial information (polygons defining parcel borderlines). The use of multispectral images with high spatial resolution would assist these assignations. In this work, new image-fusion methods are presented and described. These methods, based on the use of the discrete wavelet transform (DWT), are improved alternatives of the standard Intensity-Hue-Saturation (IHS) or Principal Component Analysis (PCA) mergers. Quantitative indicators have been used to assess the spectral and spatial quality of the images resulting when IHS - PCA standard mergers and IHS - PCA improved mergers are used to fuse SPOT images. Finally, the utility of these merged images for obtaining "crop distribution maps" via a supervised classification has also been tested. We used ground data to classify the original and the merged images, and also to analyze the accuracy of the resulting classified images.

1 INTRODUCTION

One of the aims of this research group is to develop algorithms that can be used to assign automatically a crop to a cadastral plot or parcel, matching raster information (multispectral classified images) and vectorial information (polygons defining parcel borderlines), in order to map in detail the surface covered by different crops in irrigated areas of Navarre (Northern Spain).

The small size and/or elongated or irregular shape characterize many of the parcels in these irrigated areas. The use of multispectral images with high spatial resolution for agricultural crop detection and discrimination would assist the allocation of crops to each cadastral parcel. Multispectral and panchromatic image fusion is a widely used solution to obtain high spatial and spectral resolution images.

Some of the most popular image-fusion methods are those based on the Intensity-Hue-Saturation transformation (IHS) and the Principal Component Analysis (PCA). The main drawback of these "Component Substitution" methods (Shettigara, 1992) is the high distorsion of the original spectral information that the resulting multispectral images present.

Several researchers (Garguet-Duport *et al.*1996, Yocky 1996, Wald *et al.* 1997, Nuñez *et al.* 1999, Ranchin *et al.* 2000) have compared different panchromatic and multispectral image-fusion procedures, and have proved that those based on multiresolution analysis and wavelet transforms provide an improved spatial resolution image, while keeping the spectral properties of the original data.

The above-mentioned assumption is essential for our purpose -to obtain "crop distribution maps"-.

First of all, we present and describe new image-fusion methods developed by this research group. These methods, based on the use of the discrete wavelet transform (DWT) and the multiresolution analysis (MRA) are improved alternatives of the standard IHS or PCA mergers.

Secondly, we analyze both the spectral and the spatial quality of the merged images obtained applying different image-fusion methods. In order to assess the quality of each method we have used spatially degraded SPOT 4 images.

Thirdly, we present the results obtained applying different image-fusion methods to two couple of non-degraded images: the first consisting of multispectral and panchromatic images (SPOT 4 XI and SPOT 4 M) from the same date (November 4th, 1999) and the second consisting of images from different dates (the SPOT 4 XI of November 4th, 1999 and the SPOT 2 P of August 29th, 2000).

Finally, we test the utility of all these merged images for the purpose of obtaining "crop distribution maps" via a supervised classification.

These are the objectives of this work:

a.- Compare the results obtained by using different fusion methods based on multiresolution analysis and wavelet transforms, regarding how much of the spectral information is kept in the merged image with respect to the original multispectral one, and how much of the spatial information of the panchromatic image is added to the multispectral one.

b.- Compare the synthesized images obtained when merging images collected on the same day with those obtained by merging images collected on different dates.

c.- Compare and evaluate the accuracy of the "crop distribution maps" obtained via supervised classification of the original image, and via supervised classification of the different merged images.

2 IMAGE FUSION METHODS (Applied to SPOT 4 spatially degraded images)

The SPOT 4 XI and SPOT 4 M images have been co-registered and degraded to 40m and 20m respectively. The resulting images are very close to what the corresponding sensor would have observed with a degraded resolution. This approach allows us to assess the spectral and spatial quality of the merged images (20m resolution), comparing these to the original SPOT 4 XI image.

We have used five different methods to merge the SPOT 4 XI^{40m} and the SPOT 4 M^{20m} spatially degraded images. All these methods are based on the dissociation of the spatial information of an image from the spectral information of the same image.

The spatial information of a multispectral image is dissociated from its spectral information when IHS or PCA mergers are used. In the same way, the spatial information of a panchromatic image is dissociated from its spectral information when methods based on the DWT are used.

A.- Component Substitution methods: IHS and PCA standard methods. These transformations separate the spatial information of the multispectral image into the Intensity (I) and First Principal Component (PC^1) respectively. The higher spatial resolution image replaces the I or the PC^1 component. Its spatial (and also spectral) information is inserted into the multispectral image through the IHS-RGB transformation or the inverse PCA.

B.- Method based on the multiresolution analysis (MRA) proposed by Mallat, 1989. The multiresolution analysis based on the wavelet theory allows extracting from the panchromatic image just the spatial detail information non-present in the multispectral image, to later insert that detail information into this multispectral image. The following diagram shows how this method has been applied to the SPOT 4 XI and SPOT 4 M spatially degraded images.

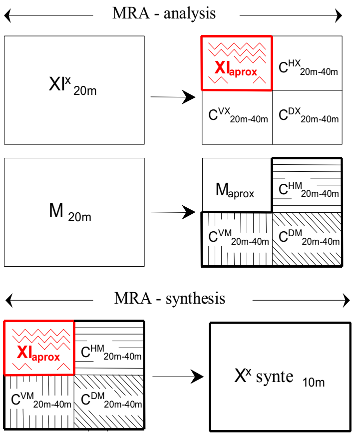


Figure 1. MRA-Substitution method applied to the SPOT 4 spatially degraded multispectral and panchromatic images

The steps for merging images using the MRA-Substitution method are:

1.- Generate new panchromatic images, whose histograms match those of each multispectral band.

2.- Apply the DWT to the "histogram-matched" panchromatic image. Apply the same decomposition to each multispectral band, using the Daubechies four-coefficient wavelet basis. (Fig. 1).

From each multispectral and panchromatic 20m-resolution image decomposition, four half-resolution images are obtained. The first one, YY_{aprox}, is a low frequency version of the original image, and the other three images or coefficients (C^{HYY},C^{VYY},C^{DYY}) pick up the horizontal, vertical and diagonal detail between the original image at resolution "r" and the approximation image (YY_{aprox}) at resolution "r/2". To pass from a resolution level to the next lower resolution level, a filtering procedure followed by subsampling is used (MRA concept, described by Mallat, 1989).

3.- Introduce the detail coefficients of the panchromatic image into each XI band through the inverse DWT, in this phase filtering and resampling, and obtain the final merged or synthesized image, with a spatial resolution of 20 meters.

This image-fusion method has been used by Ranchin *et al*, 1993; Mangolini *et al*, 1994; Yocky, 1996; Gauguet-Duport *et al*, 1996; Zhou *et al*; 1998 and Ranchin & Wald, 2000, amongst others.

C.- IHS and PCA improved methods (MRA-IHS and MRA-PCA). The basic idea of these new methods is to use the MRA to insert in the PC^1 or Intensity component just the spatial information of the panchromatic image that is missing in the multispectral image.

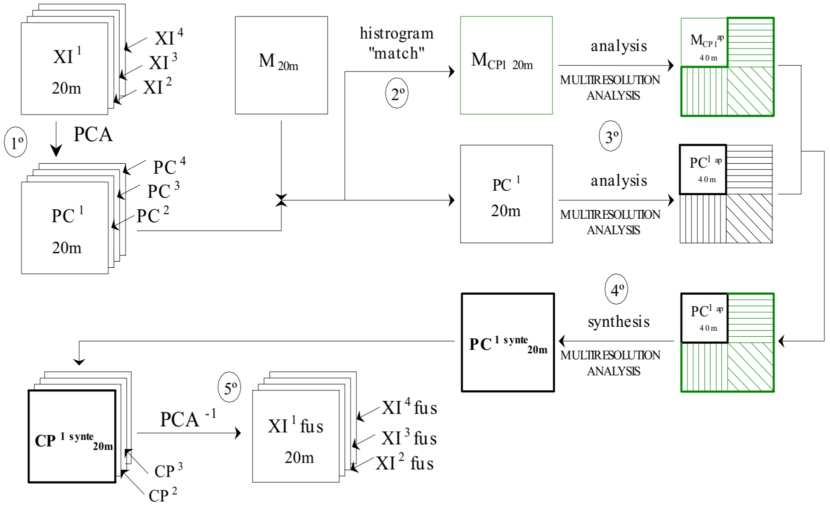


Figure 2. MRA-PCA method application diagram, for the fusion of the SPOT 4 XI and SPOT 4 M spatially degraded images.

The steps for merging images using the MRA-IHS or the MRA-PCA methods are the following:

1.- Apply the PCA or the IHS transform to the multispectral image. These transformations separate the spatial information of a multispectral image into the PC^1 or Intensity components respectively.

2.- Generate a new panchromatic image, whose histogram matches the histogram of the PC^1 or Intensity image.

3.- Apply the MRA using the DWT to the PC^1 or Intensity image and to the corresponding "histogram-matched" panchromatic one. Both decompositions are computed using the Daubechies four-coefficient wavelet basis.

Extract the wavelet coefficients that pick up the horizontal, vertical and diagonal spatial detail present in the panchromatic image and missing in the multispectral one.

4.- Introduce this spatial detail information into the PC^1 or Intensity image through the inverse DWT. (Fig. 2)

5.- Insert the spatial information of the panchromatic image between 20 m and 40 m in the multispectral one through the inverse PCA or the IHS-RBG transform. The result is a merged or synthesized image with high spectral and spatial resolution.

2.1 *Spectral quality of the merged images.*

Synthesized images obtained by different methods have a spatial resolution of 20 m, so their spectral quality can be evaluated by comparing its spectral information to that of the original SPOT 4 XI image. In doing so, it is possible to determine which method produces a higher spectral quality image.

The spectral quality assessment procedure is based on visual inspection and the use of the following quantitative indicators:

a.- Correlation coefficient between the original and the merged images. Best values, near 1.

b.- The bias, or difference between the means of the original and the merged image (radiance values, $W/m^2{*}sr$). Best values, near 0.

c.- The standard deviation of the difference image (radiance values, $W/m^2{*}sr$). Best values, near 0.

d.- The Relative Average Spectral Error (RASE), expressed as a percentage. It characterizes the average performance of the method in the considered spectral bands (Ranchin *et al*. 2000):

$$RASE = \frac{100}{M}\sqrt{\frac{1}{N}\sum_{i=1}^{n}(RMSE(B_i))^2}$$

where M is the mean radiance of the N original multispectral images B_i, and the *RMSE* is the Root Mean Square Error computed following the expression:

$$RMSE(B_i)^2 = bias(B_i)^2 + stand.deviation(B_i)^2$$

e.- The ERGAS index, (*Erreur Relative Globale Adimensionnelle de Synthèse*), or relative adimensional global error in synthesis (Wald, 2000[b]), expressed as a percentage:

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{i=1}^{n}\left[\frac{(RMSE(B_i))^2}{M_i^2}\right]}$$

where h is the resolution of the high spatial resolution image (panchromatic image) and l the resolution of the low spatial resolution image (multispectral image). Best values, less than 3 (Wald, 2000[a]).

Table 1 shows the results obtained for the indexes described above when the SPOT 4 XI^{40m} - SPOT 4

M^{20m} merged images are compared to the SPOT 4 XI^{20m} original image. The bar diagrams show graphically the correlation between these images. All of them correspond to the "Funes" irrigated area, in the South of Navarre (Spain).

The '*XI-40m'* column shows the results that refer to the comparison between the SPOT 4 XI^{40m} spatially degraded image (initial multispectral image for the fusion) and the SPOT 4 XI^{20m} original multispectral image.

Lower correlation coefficients or higher ERGAS values than those showed in the first column indicate that the image-fusion procedure tends to modify the spectral information of the multispectral image, while higher correlation coefficients and lower ERGAS values imply that the fusion method used allows a "high quality transformation of the multispectral content when increasing the spatial resolution" (Ranchin & Wald, 2000).

Table 1. Spectral quality of the merged images **SPOT 4 XI^{40m} – SPOT 4 M^{20m}** using different methods

		XI - 40m	IHS	PCA	MRAsubs	MRA-IHS	MRA-PCA	*IDEAL*
Spectral correlation coefficient	X1	*0.974*	0.8955	0.9651	0.9873	0.9863	0.9876	*1*
	X2	*0.980*	0.9593	0.9725	0.9904	0.9933	0.9935	*1*
	X3	*0.973*	0.7017	0.9714	0.9522	0.9638	0.9746	*1*
	X4	*0.976*	0.9065	0.9556	0.9781	0.9819	0.9819	*1*
RASE		*6.72 %*	15.38 %	7.16 %	6.55 %	5.79 %	5.09 %	*0*
ERGAS		***2.951***	**6.37**	**3.508**	**2.784**	**2.480**	**2.281**	***0***

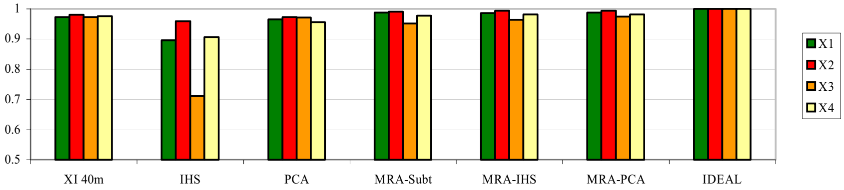


Figure 3. Spectral correlation between merged images and the original SPOT 4 XI image

** IHS standard or improved methods have been applied to the four possible RGB combinations, so three synthesized images have been obtained for each multispectral band. The synthesized bands selected to create the multispectral merged images were those that had the highest correlation with the corresponding one in the SPOT 4 XI original image

2.2 *Spatial quality of the merged images*

To evaluate the spatial quality of the merged images, we used the procedure proposed by Zhou *et al*, (1998). The panchromatic SPOT 4 M^{20m} image and the merged images, are filtered using a Laplacian filter.

A high correlation between the merged filtered image and the panchromatic filtered one indicates that many spatial information from the panchromatic image has been incorporated during the merging process (Zhou *et al*, 1998).

Table 2. Spatial quality of the different merged images. **SPOT 4 XI^{40m} – SPOT 4 M^{20m}**

		XI - 40m	IHS	PCA	MRAsubs	MRA-IHS	MRA-PCA	*XI-20m IDEAL*
Spatial correlation coefficient	X1	*0.6018*	0.9012	0.9709	0.9047	0.8898	0.8966	0.8731
	X2	*0.6529*	0.9142	0.9755	0.9135	0.9367	0.9286	1.0000
	X3	*0.1993*	0.7263	0.5139	0.6333	0.5404	0.4252	0.2763
	X4	*0.4930*	0.9472	0.9597	0.7914	0.8343	0.8369	0.6812

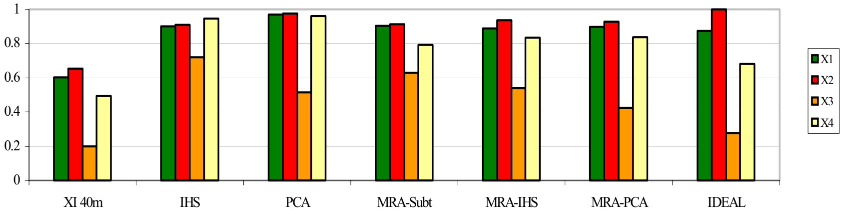


Figure 4. Spatial correlation between merged images and the SPOT 4 M^{20m} panchromatic image

The results of this spatial quality assessment are displayed in Table 2. The first column shows the spatial correlation between the panchromatic and the initial SPOT 4 XI^{40m} multispectral image. The last one shows the spatial correlation coefficients between the panchromatic and the real multispectral image.

The bar diagram (Fig. 4) shows graphically the correlation coefficient between these synthesized images and the filtered panchromatic one.

Correlation coefficients higher than those showed in the last column indicate that during the image-fusion procedure more spatial detail information has been incorporated to the multispectral image than that actually present in the multispectral image when observed by the corresponding sensor with a spatial resolution similar to the panchromatic one.

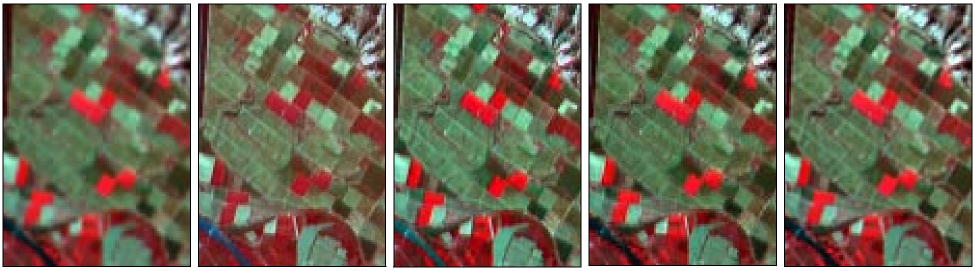

(a) SPOT 4 XI 40m **(b)** IHS standard Synthesized, 20m **(c)** PCA standard Synthesized, 20m **(d)** MRA-PCA Synthesized, 20m **(e)** SPOT 4 XI Original, 20m

Figure 5. On the left, the multispectral initial image. On the right, the original SPOT 4 XI image, i.e. the ideal synthesized image. In between, the synthesized images applying different methods

2.3 *Image-fusion methods comparison*

The IHS standard method gives poor results both spectrally and spatially. There is an excessive incorporation of information from the panchromatic image into the multispectral one, and this results in a low spectral quality of the merged image. This fact can be observed in the color of the crop fields and in the appearance of the river (left-bottom part, Fig. 5(b)) in comparison with the same areas in Fig. 5(a).

The PCA standard method performs better, but the spectral content of the merged image is significantly different from that of the SPOT 4 XI original one. The RASE and ERGAS values are higher after the fusion (7.16% and 3.51 respectively) than before (6.72% and 2.95). This indicates that the image-fusion procedure has modified the spectral information of the multispectral image when increasing its spatial content.

All the methods based on the MRA provide high spectral quality images. In all cases, the RASE and ERGAS values are lower after the fusion than before. This leads to the conclusion that those methods preserve the spectral information of a multispectral image while its spatial content increases.

Spatially, the MRA-PCA method performs best. In the MRA-Substitution case, there is an excessive spatial detail incorporation in the NIR band and this results in a lower spectral correlation of this band with the corresponding one in the SPOT 4 XI original image.

3 ORIGINAL AND MERGED IMAGES CLASSIFICATION

All the methods described before have been applied to fuse SPOT 4 XI^{20m} - SPOT 4 M^{10m} and SPOT 4 XI^{20m} - SPOT 2 P^{10m} non-degraded images. The first pair of images was collected on the same date (November, 1999), while the two images in the second pair were collected in different years and seasons (November, 1999 and August, 2000). The following tables show the results obtained from applying the spectral and spatial quality assessment to these merged images, (degraded after de fusion to 20 m and compared to the multispectral SPOT 4 XI original image).

Table 3.- Spectral and spatial quality of the different merged images. SPOT 4 XI – SPOT 4 M. Same date

		IHS	PCA	MRAsub	MRA-IHS	MRA-PCA
Spectral correlation coefficient	X1	0.867	0.952	0.983	0.985	0.986
	X2	0.946	0.956	0.986	0.987	0.988
	X3	0.630	0.978	0.977	0.978	0.984
	X4	0.834	0.948	0.985	0.985	0.986
RASE		13.21 %	8.23 %	5.52 %	5.04 %	5.03 %
ERGAS		**6.64**	**4.20**	**2.48**	**2.45**	**2.34**
Spatial correlation coefficient	X1	0.8506	0.9577	0.7302	0.7176	0.7257
	X2	0.9104	0.9704	0.8427	0.7978	0.7875
	X3	0.7778	0.5272	0.4329	0.4534	0.3418
	X4	0.8721	0.9488	0.5610	0.6025	0.6202

The values of the spatial correlation coefficient between the original SPOT 4 XI^{20m} image and the panchromatic SPOT 4 M^{10m} filtered images are 0.452, 0.568, 0.125, and 0.287 for each spectral band.

Table 4.- Spectral and spatial quality of the different merged images. SPOT 4 XI – SPOT 2 P. Different dates

		IHS	PCA	MRAsub	MRA-IHS	MRA-PCA
Spectral correlation coefficient	X1	0.445	0.685	0.982	0.982	0.983
	X2	0.672	0.571	0.985	0.986	0.988
	X3	0.387	0.905	0.979	0.978	0.983
	X4	0.472	0.680	0.984	0.984	0.984
RASE		29.59%	20.78 %	5.39 %	4.94 %	5.15 %
ERGAS		**14.57**	**11.13**	**2.46**	**2.44**	**2.41**
Spatial correlation coefficient	X1	0.7584	0.9331	0.3738	0.3706	0.3722
	X2	0.7739	0.9472	0.3938	0.3799	0.3931
	X3	0.7439	0.4868	0.3102	0.2924	0.2237
	X4	0.7521	0.9244	0.3042	0.3123	0.3290

The spatial correlation coefficient values between the original SPOT 4 XI^{20m} image and the panchromatic SPOT 2 P^{10m} filtered images are 0.077, 0.108, 0.027 and 0.0165 for each spectral band.

For the merging of both datasets, the methods based on the MRA provide high spectral quality images, regardless of the date difference between the multispectral and panchromatic images being fused.

In contrast, the results obtained applying the IHS and PCA standard methods are very influenced by the difference in the acquisition dates of the images to fuse, as the ERGAS values in tables 3 and 4 demonstrate. If these images are acquired in different seasons, the spectral quality of the merged images obtained using these procedures is really poor.

3.1 *Supervised classification*

So far we have assessed the quality of the merged images resulting from the application of different methods using statistical and quantitative indexes.

The last objective of this work is to evaluate the utility of these merged images to obtain “crop distribution images” via a supervised classification.

We have used ground data to classify the original and the synthesized images. These ground data comprise a crop map depicting the crop on each parcel. It was obtained by surveying 100 per cent of the parcels of the embraced area. The field survey dates were November 6th and 7th, 1999.

About 25 per cent of this information is randomly selected and used as training sites. The statistics of these training sites have been used to estimate the *a priori* probability of each crop.

These statistics have been also used to determine the typicality of all the pixels belonging to any training site. The typicality is a measure of how typical of its class a pixel is (Foody et al, 1992), and is inversely related to the distance between the pixel and its class centroid.

To increase the classification accuracy, pixels corresponding to training sites that have a low typicality are not used in the final classification. It must be pointed out that, in this case, the majority of pixels with low typicality are pixels from the borderlines of parcels, and therefore mixed pixels.

We have used Maximum-Likelihood classification, considering different *a priori* probabilities for each class, calculated as mentioned previously. Different “crop distribution maps” were obtained from the classification of the original and the merged images created using the various methods described.

3.2 *Classified images accuracy*

To correctly perform classification accuracy assessment, it is necessary to compare two sources of information (Jensen, 1996):

- The remote-sensing-derived classification maps, obtained by classifying the original and merged images.
- The “reference test image”. This image has been obtained using all the ground information corresponding to all the parcels of the “Funes” irrigated land.

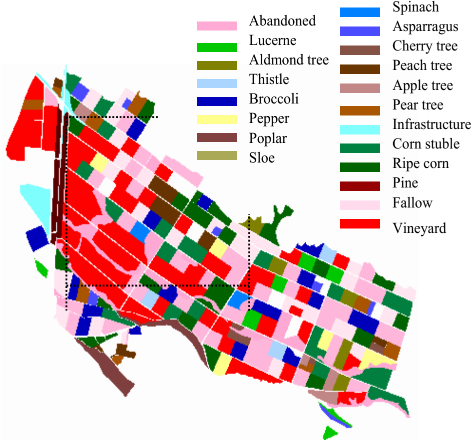


Figure 6. “Reference test image”, obtained surveying a hundred percent of the parcels (Funes irrigated area covers 835.90 ha)

The result of the comparison of these two sets of information is summarized in the “error matrix”.

The overall accuracy of each classification is computed dividing the sum of pixels of the major diagonal by the total number of pixels in the error matrix.

The accuracy of each class has been obtained using the following parameters:

- User’s accuracy: percentage of pixels that the classified image predicts to belong to a particular class that the “reference test image” verifies to be correct.
- Producer’s accuracy: percentage of pixels belonging to a particular class in the “reference test image” that were classified correctly
- Hellden index (HI): reflects the user’s and the producer’s accuracy combined, and it is cal-

culated dividing the correctly classified pixels corresponding to a class by the sum of all the pixels assigned to that class, both in the classified image and in the reference test image.

For each classified image, we have computed all these parameter values for the vineyard (VIN) and broccoli (BRO) classes. These two crops have been selected for their high abundance in this irrigated area as well as for their high economic value.

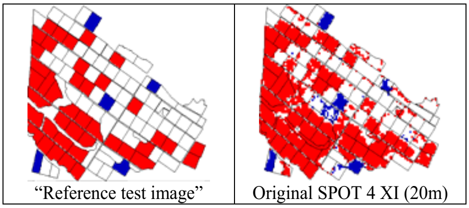
Table 6. Accuracy values (HI) for the original and SPOT 4 XI – SPOT 4 M merged images, expressed as percentage

	Original	IHS	PCA	MRAsub	MRA-IHS	MRA-PCA
HI- bro	*74.26*	64.66	75.20	79.60	79.37	80.23
HI - vin	*69.81*	74.95	74.60	75.31	75.37	76.03

Table 7. Accuracy values (HI) for the original and SPOT 4 XI – SPOT 2 P merged images, expressed as percentage.

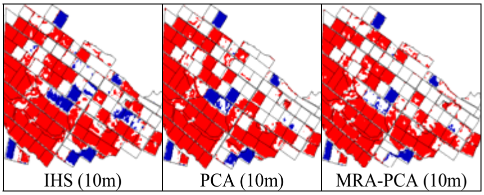
	Original	IHS	PCA	MRAsub	MRA-IHS	MRA-PCA
HI- bro	*74.26*	67.32	69.01	79.46	79.53	79.71
HI - vin	*69.81*	77.43	78.76	75.22	75.31	75.27

Figure 7 shows the spatial location of the pixels classified as **vineyard** and as **broccoli** in the original and various merged images (corresponding to the area marked in Fig. 6)



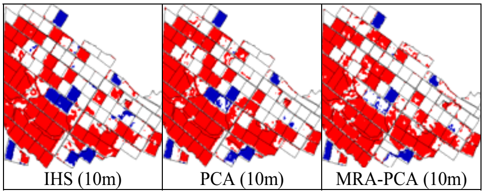
"Reference test image" Original SPOT 4 XI (20m)

SPOT 4 XI – SPOT 4 M merged images. Same date



IHS (10m) PCA (10m) MRA-PCA (10m)

SPOT 4 XI – SPOT 2 P merged images. Different dates



IHS (10m) PCA (10m) MRA-PCA (10m)

Figure 7. Spatial location of vineyard and broccoli in the original and merged classified images

Unfortunately, this HI provides non-site-specific accuracy assessments that ignore the locational accuracy. This locational accuracy has been analyzed indirectly by checking the number of parcels that could be erroneously classificated if a majority algorithm was used to allocate automatically vineyard or broccoli to each cadastral parcel.

Tables 8 and 9 indicate the erroneously classified parcels in the original and merged images shown in Figure 7.

Table 8. Broccoli and vineyard erroneously classified parcels in the original and the SPOT 4 XI – SPOT 4 M merged images

	Original	IHS	PCA	MRA-PCA
Broccoli parcels	*1*	3	1	0
Vineyard parcels	*9*	8	8	8

Table 9. Broccoli and vineyard erroneously classified parcels in the original and the SPOT 4 XI – SPOT 2 P merged images

	Original	IHS	PCA	MRA-PCA
Broccoli parcels	*1*	3	2	0
Vineyard parcels	*9*	3	6	8

The original SPOT 4 XI image classification presents high user's accuracy for broccoli (71.29%). This leads to few erroneously classified parcels (1 in this case) using majority-allocating algorithms. On the other hand, user's accuracy for vineyard is 57.66%, leading to many erroneously classified parcels (9 in this case).

When HSI and PCA standard mergers are applied, I and PC^1 images are replaced by a panchromatic image, so there is a change in the spectral content of the original multispectral image.

In the first case, SPOT 4 XI and SPOT 4 M image fusion, there is a loss of spectral information; information in the visible and infrared channels is replaced by information from a visible channel only.

In the second case, SPOT 4 XI and SPOT 2 P image fusion, there is a loss of infrared channel information but also an addition of spectral information collected on two different dates. Vineyard is a permanent crop, this being the reason why the accuracy for vineyard is higher in the classified images by these methods, and less the erroneously classified parcels (3 for HSI and 6 for PCA). When using two different date images, permanent crops (like vineyard) could be detected and distinguished more easily than non-permanent crops or short cycle crops, like broccoli, which could be distinguished in a November image but not in an August image.

Analyzing the results shown in tables 6 to 9 and figure 7, it is possible to affirm that the fusion of SPOT XI multispectral and panchromatic images using methods based on the multiresolution analysis and the DWT improves the accuracy in the classification of different crops. This accuracy improvement is due to a higher spatial resolution of the merged images, and it is independent of the date difference between the multispectral and panchromatic images to fuse.

4 CONCLUSION

The new multispectral and panchromatic image-fusion methods based on the DWT and proposed in this work (MRA-IHS, MRA-PCA) are capable of enhancing the spatial quality of the multispectral image, while preserving its spectral content. This preservation is higher if the panchromatic image is adjusted to match the mean and the variance of each component (I or PC^1) before merging.

Synthesized images obtained using the above mentioned methods are suitable to get "crop distribution images" via supervised classification. The accuracy of the classified images from the merged images (with its spatial resolution improved) is higher than the accuracy of the classified image resulting from the classification of the original one.

The improvement of accuracy is due to a higher spatial resolution, and leads to a lower number of erroneously classified parcels if a majority algorithm is used to assign a crop to each cadastral parcel. Moreover, this accuracy improvement is independent of the difference in the acquisition dates of the images to merge.

The accuracy of the merged spectrally classified image, compared to the accuracy of the original classified image is not a very precise parameter to analyze the spectral quality of a merged image, because it depends too much on factors such as the date when the images were collected, the sensor system characteristics, the type of landscape, its diversity or the type of classifier used.

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