Comparison of the spectral and spatial information content of pansharpened TM and XS images

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Abstract

According to their optical appearance and interpretation a pansharpened TM image and a pansharpened XS image (the same panchromatic image is used in both fusion cases) seem to be identical. In this paper a question was set, referring to whether these two images are actually the same and to whether a researcher can use either of them in land cover classification applications, obtaining the same results. To answer this question, the spectral information and the spatial accuracy of the synthetic images, as well as, their land cover classification products were investigated and compared. For the comparison of all the above, methods as the study of the entropy of the synthetic images, the study of the error matrices of their classification, as well as raster GIS operations between the classified images, were used. The investigation, led to the conclusion that whatever the origin of the synthetic images is, the products obtained are of the same value.

1. Introduction

Since 1972, the year Landsat-1 was orbited, a huge number of images coming from different sensors and different areas of spectrum, with various radiometric resolutions and especially various spatial resolutions has been acquired. For the full exploitation of this rich material a great number of studies concerning the possibility of the combination of these images through fusion techniques took place (e.g. Cliché *et al.* 1985; Welch and Ehlers 1987; Chavez *et al.* 1991; Pellemans *et al.* 1993; Yesou *et al.* 1993; Pohl and van Genderen 1998; Antunes 2000; Wald 2001; Rancin *et al.*2003, Nikolakopoulos 2008). A high percentage of these studies refer to the comparison of the synthetic images to the corresponding original, as well as, to the advantages of using a synthetic image in remote sensing applications. (e.g. Pellemans *et al.* 1993; Antunes 2000; Wald 2001; Zhang 2003). However, despite its significance, a research subject that does not seem (according to current bibliography) to concern the remote sensing community, is the comparison of two synthetic images of equal spectral and spatial resolution, that depict the same geographic area, have the same acquisition date, stem from the same panchromatic image, but from different original multispectral images. The significance of this subject rests on the fact that if the images under comparison are proved similar a researcher is allowed to use either of them in land cover classification applications.

The main objective of this paper is the comparison of a pansharpened TM to a pansharpened XS image, which fulfill the description mentioned above, with a view to the investigation of their spectral and spatial similarity and especially with a view to the assessment of the similarity of their land cover classification products. Initially, the extent of their similarity was optically interpreted and afterwards using statistical methods and raster GIS operations their agreement was estimated.

The study area, that is included in the pansharpened images under investigation, comprises urban, suburban and forest parts of Thessaloniki, Greece. In this particular area a great part of the forest was destroyed by fire in July 1997.

The original images depicting the study area are:

- a panchromatic image of SPOT2 with a spatial resolution of 10 m and acquisition date 8/27/1997
- a multispectral XS image of SPOT4 with a spatial resolution of 20 m and acquisition date 8/28/1998
- four bands of the multispectral TM of LANDSAT-5 image with a spatial resolution of 30 m and acquisition date 7/27/1997

As seen above, the XS SPOT4 image was acquired one year later than the PAN SPOT2 and the LANDSAT-5 TM. However, for the certain study area there were no changes in land cover (no reforestation of the burnt area took place and there were no other changes in forest cover and other land uses as it was verified by spot tests). So, for the specific study, the 1998 XS SPOT4 was considered as of the same acquisition year with the rest of the original data. The software used for the whole procedure was ERDAS IMAGINE 7.0

Taking into account that a TM LANDSAT image covers 185×185 Km^2, an XS SPOT covers 60×60 Km^2 and a PAN SPOT image covers 60×60 Km^2, it is understood that a pansharpened TM (1 TM and 9 PAN images are needed for its construction) costs much less than a pansharpened XS of the same area (9 XS and 9 PAN images are needed). This makes the interest for the results of this study much bigger.

2. Processing of the original data and creation of the pansharpened images

The two synthetic images, were created through the fusion of the panchromatic image PAN SPOT2 with the multispectral image LANDSAT-5 TM and the fusion of same panchromatic image with the multispectral XS SPOT4. Not all the bands of the TM image were used but only the bands 2, 3, 4 and 5, that correspond, as far as their spectral range is concerned, to the bands 1, 2, 3 and 4 of XS SPOT4 image (e.g.Yesou *et al.* 1993; Tsakiri-Strati *et al.* 2002a). The selection of only four TM bands targeted to an even spectral resolution of the two original images and eventually to similar synthetic images.

Since most of the study area is mountainous and of a steep slope, the orthorectification (e.g. LPS 2005) of the images preceded (Tsakiri-Strati *et al.* 2002b). The orthorectification (when necessary) improves the spatial accuracy of the original images and consequently, improves and emulates the spatial accuracy of all the following products. Therefore, the desirable agreement of the synthetic images under comparison is served. For the orthorectification procedure, a Digital Terrain Model of the study area in Universal Transverse Mercator (UTM) coordinates (e.g. Fotiou 2007) was used. The orthorectification was followed by the registration of the orthorectified TM and XS images on the orthorectified panchromatic image PAN SPOT2, using an affine transformation (e.g. Paraschakis *et al*. 1990).

The fusion procedure was accomplished by the technique of the Principal Component Analysis (PCA) (e.g. Chavez *et al.* 1991, Pohl and van Genderen 1998, Li 2000). This method, according to Tsakiri-Strati *et al.* (2002a), proved to be the most appropriate method for the fusion of a PAN SPOT2 with an XS SPOT4. The use of the PCA method for the fusion of the LANDSAT-5 TM with the PAN SPOT2 image, rested on Yesou *et al.* (1993), according to whom the PCA technique proved to be effective for the fusion of a TM with a PAN image. In the fusion procedure the orthorectified images were used. The synthetic products, symbolized as TM-PAN and XS-PAN respectively, have the same radiometric (8-bit), spatial (10 m) and spectral resolution (four bands).

3. Comparison of the fusion products

The required investigation was accomplished through the following procedures:

- The evaluation of the quantity of information as well as the evaluation of the spectral and spatial similarity of the synthetic images (§3.1, §3.2, §3.3).
- The estimation of the land cover classification accuracy and the assessment of the land cover classification products of the two synthetic images (§4.1, §4.2, §4.3, §4.4).

In order the spectral similarity of the pansharpened images to be evaluated, at first, there was a matching of the histogrammes of TM bands to the histogrammes of the corresponding XS bands (Tsakiri-Strati *et al.* 2002a).

3.1. Quantity of information. The entropy of the pansharpened images

For the assessment of the included information, the entropy E (e.g. Moik 1980; Gonzales and Woods 1993; Mather 1999; Schenk 1999; Leung *et al.* 2001) of each synthetic image was calculated. Many researchers in the scientific field of image processing have used the entropy E of an image, as a statistical characteristic of its information content (e.g., Leung *et al.* 2001; Barbieri *et al*. 2009; Kerke *et al.* 2010). The entropy is measured in bits and is calculated by the following formula (e.g. Schenk 1999; Skidmore 2002)

$$E = -\sum_{1}^{256} P(i) \log_2 P(i) \tag{1}$$

where $P(i)$ is the frequency of the appearance of the i-bit level in every band.

In table 1 the entropy of the original, as well as, the synthetic images is depicted. According to the table, the entropy of the XS-PAN image equals to 25.209. This value is almost equal to the value of the original XS. On the other hand, the entropy of the original TM shows a significant improvement in each band and totally. The entropy of the synthetic TM-PAN becomes equal to 24.599 and is almost equated to the entropy of the XS-PAN, while the entropy of the original TM image was only 18.520.

Table 1: *The entropy of each band and the total entropy of the original and the pansharpened images. The synthetic images are adequately the same*

image	entropy				
	bands				total
	1	2	3	4	
PAN SPOT2	6.175				6.175
XS SPOT4	6.629	6.551	6.468	5.397	25.044
Landsat-5 TM	3.994	4.612	4.766	5.149	18.520
XS-PAN	6.213	6.397	6.213	6.387	25.209
TM-PAN	5.840	6.067	6.414	6.278	24.599

3.2 Evaluation of the spectral similarity of the pansharpened images

The spectral similarity of the two synthetic images is described through the correlation coefficients of their four corresponding bands and the correlation coefficients that come from all the combinations of two bands in every image (see table 2). Table 2 shows a very satisfactory relation between the corresponding bands, since in all cases the correlation coefficients (diagonal numbers in the sub matrices created by the combination of TM-PAN and XS-PAN), are almost equal to 1 (0.963, 0.999, 0.967, 0.989). It is also worth stressing, that the internal relation of the bands of each image in combinations of two, which is described by their correlation coefficient, is kept the same in both images. For example, the correlation coefficient between band 1 and band 2 of XS-PAN is 0.622. The corresponding correlation coefficient that describes the internal relation between band 1 and band 2 of TM-PAN, is equal to 0.673, which is very close to 0.622. As depicted in table 3, all the correlation coefficients between two bands in every image (bold numbers in the two sub matrices created by TM-PAN bands or by XS-PAN bands) are numbers very close to each other. According to the content of table 2 and to Tsakiri-Strati *et al.* (2002b), the spectral similarity of the new images exists.

Table 2: *Table of correlation coefficients between all the bands in combinations of two in each pansharpened image (depicted in bold) and correlation coefficients of the corresponding bands of the pansharpened images (depicted in grey cells).*

		XS-PAN bands				TM-PAN bands			
		1	2	3	4	1	2	3	4
XS-PAN bands	1	1.000	**0.673**	**0.710**	**0.623**	**0.963**	0.672	0.744	0.606
	2	0.673	1.000	**0.933**	**0.727**	0.624	**0.999**	0.971	0.722
	3	0.710	0.933	1.000	**0.704**	0.684	0.936	**0.967**	0.716
	4	0.623	0.727	0.704	1.000	0.585	0.733	0.716	**0.989**
TM-PAN bands	1	**0.963**	0.624	0.684	0.585	1.000	**0.622**	**0.704**	**0.573**
	2	0.672	**0.999**	0.936	0.733	0.622	1.000	**0.971**	**0.727**
	3	0.744	0.971	**0.967**	0.716	0.704	0.971	1.000	**0.710**
	4	0.606	0.722	0.716	**0.989**	0.573	0.727	0.710	1.000

3.3. Evaluation of the spatial similarity of the pansharpened images

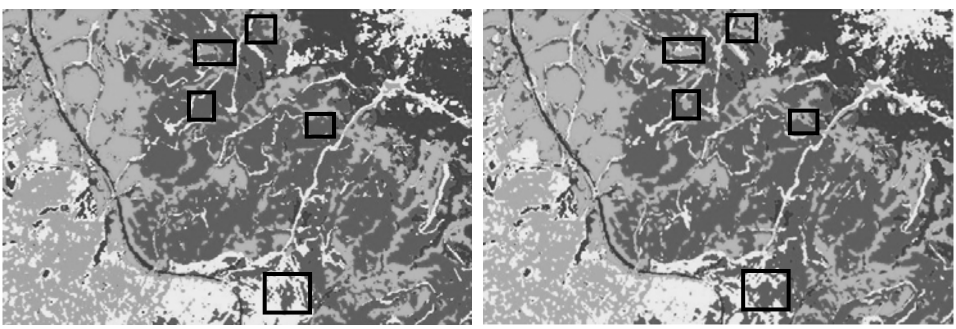
In order the spatial similarity of XS-PAN and TM-PAN to be evaluated, their geometrical accuracy was tested (Tsakiri-Strati *et al.* 2002a) through a registration of both pansharpened images on the orthorectified panchromatic PAN SPOT2. The registration of each image was accomplished using the affine transformation and exactly the same control points (position and number). The registration of the TM-PAN gave a Root Mean Square (RMS) error equal to 0.45 m and the registration of the XS-PAN gave an RMS error equal to 0.50 m. At this point must be stressed, that according to Tsakiri *et. al*. (1998), the spatial and spectral resolution of the remote sensing data in use, allow a range of study scale at 1:50000 or smaller. Considering the study scale allowed, both RMS errors were accounted equal. The equation of the RMS errors indicates that the two images have the same spatial accuracy and therefore spatial similarity. This specific accuracy is also very satisfactory for the next steps of the investigation.

4. Comparison of the classification of the two pansharpened images

4.1 Land cover classification of the pansharpened images

For the supervised classification of the synthetic images the maximum likelihood technique (e.g. Mather 1999*)*, which is a widely used method, was applied. The samples used, were exactly the same and six land cover categories were created for both images, the following: major road, urban area, forest area, vegetation, burnt forest area, forest road-uncovered area (see figure 1a, 1b). Further, the two classified images are symbolized as CL-XS-PAN and CL-TM-PAN respectively.

The optical observation of the figures gives the sensation that the classified images have a significant agreement. Some occult differences exist, as for example in the areas surrounded by the black frames. As observed, the most mixed land cover categories seem to be the urban area, the forest road-uncovered land and the burnt forest area.



(a) (b)

Figure 5: *The classified synthetic image CL-TM-PAN. and CL-XS-PAN. The areas enclosed in the black frames are some of the ones that introduce disagreement between CL-XS-PAN and CL-TM-PAN.*

4.2 Comparison of the classification characteristics

Through the analysis of the two classification error matrices, the degree of resemblance between classified categories was estimated. The use of the error matrix (e.g. Moik 1980) contents in the comparison of two classifications is a standard procedure (e.g. Congalton and Green 1999; Cambell 2002; Skidmore 2002;).

The overall classification accuracy of CL-XS-SPOT was calculated equal to 88%, while the corresponding Kappa coefficient K1 was calculated equal to 0.8483. The overall classification accuracy of CL-TM-PAN was calculated equal to 83%, while the corresponding Kappa coefficient K2 was calculated equal to 0.7969. The values of the statistical coefficients K1 and K2 are both very close to 0.80. These values show that the two classifications have strong accordance to the reference data.

Next, the coefficients K1 and K2 were used for the comparison of the two error matrices (e.g. Congalton and Green 1999) through the calculation of the Z quantity of the normal distribution given by relation (2):

$$Z = \frac{|K_1 - K_2|}{\sqrt{\mathrm{var}(K_1) + \mathrm{var}(K_2)}} \tag{2}$$

where
K_1: the overall Kappa coefficient of the XS-PAN image classification
K_2: the overall Kappa coefficient of the TM-PAN image classification
var(K_1) and var(K_2): the estimations of the variances of K_1 and K_2 respectively

Using the Z quantity the validity of the null hypothesis H_o (H_o: K_1=K_2 and H_α: K_1< >K_2) was checked. Since the resultant Z equals to 0.86, which is less than 1.96 the null hypothesis H_o applies and the two error matrices do not differ significantly. (e.g. Skidmore 2002). This means that the two classifications do not differ significantly statisticswise.

4.3 The classification similarity in practice

One standard practical use of a classified image is the calculation of the areas of each land cover category. For this reason, the results of the area calculation from both CL-TM-PAN and CL-XS-PAN were studied. Table 3 depicts the number of pixels for each category in the two images, the corresponding areas and the absolute difference of these areas in Km^2. The differences depicted are acceptable, tak-

Table 3: *Number of pixels, areas and absolute area differences of the land cover categories in the two classified images. The areas are calculated in km^2. One pixel is equal to 100 m^2.*

	classified images				absolute difference	
	CL-XS-PAN		CL-TM-PAN			
classification categories	pixels	area (km^2)	pixels	area (km^2)	pixels	area (km^2)
forest area	46512	4.65	47406	4.74	894	0.089
burnt forest area	76466	7.65	75311	7.53	1155	0.011
forest road-uncovered land	33247	3.32	34458	3.45	1211	0.012
vegetation	26397	2.64	26986	2.70	589	0.006
major road	2363	0.24	2375	0.24	12	0.000
urban area	32578	3.26	28717	2.90	3861	0.387

ing under consideration the information detail and accuracy that the range of the allowed study scales (see §3.3) presupposes.

4.4 *Evaluation of the spatial agreement of the raster classified images*

The proof of the existence of classification similarity, is complimented and reinforced by the proof of the spatial agreement of all the pixels of classification categories. For this reason a direct contrast of the two raster classified images took place and the spatial position of the corresponding categories were checked through an operation that belongs to the analysis of a raster GIS (e.g. Laurini and Tomson 1992; NCGIA 2000; URL1). This operation was the cross-tabulation (e.g. Lembo 2000) of the classified images that comprises a pixel-by-pixel comparison of two raster layers

In relevant bibliography, cross-tabulation, is almost exclusively used in change detection applications, for the comparison of two raster information layers that depict the same phenomenon as it appears in two different time moments. (e.g. Civco *et al*. 2002). In this paper, this operation was used for the direct comparison of two contemporary raster layers, which however come from a different origin.

Cross-tabulation is a procedure that actually gives the number of the identical

Table 4: *The confusion matrix. The grey cells contain the number of pixels of total agreement. The black bold numbers indicate the most mixed categories according to the number of discrepant pixels.*

		CL-XS-PAN categories					
		major road	major road	vegetation	forest area	bumt forest area	forest road-uncovered land
CL-XS-PAN categories	major road	**1977**	116	13	238	1	30
	urban area	212	**25680**	87	227	138	**2373**
	vegetation	43	502	**23873**	583	1406	579
	forest area	117	1279	1143	**43628**	1199	40
	bumt forest area	13	**2579**	843	1832	**68891**	**2308**
	forest road-uncovered land	1	**2422**	438	4	**3676**	**27917**

pixels between two corresponding classification categories (Lembo 2000). No new raster layer is derived. For the quantification of the cross-tabulation results, the confusion matrix (e.g. Lembo 2000) is calculated. Table 4 and table 5 depict the conclusions after the analysis of the derived confusion matrix. A total agreement exists between 191966 pixels (sum of the diagonal cells) that represent the 87.3% of the whole amount of 219835 pixels in each image.

Table 5: *The successful concurrence of the land cover categories in the two classified images is depicted. The best results correspond to the categories of the forest area and the burnt forest area. All percentages are over 81%.*

classification category	spatial agreement (%)
forest area	92.03
bumt forest area	90.10
urban area	89.42
vesetation	88.50
major road	83.24
forest road-uncovered land	81.02
total area	87.30

5. Discussion and conclusions

The aim of this paper was the comparison of two pansharpened images (coming from different multispectral images and the same panchromatic image), through the investigation of their spectral, spatial and classification similarities. With reference to trustworthy results, a careful elaboration of the original data took place.

Firstly, only four of the seven TM bands were selected and used for the fusion procedure, in order the TM image and XS image to get an even spectral resolution of the same spectral range in each band. Afterwards, the orthorectification of the original images took place, for the accomplishment of spatial corrections due to the steep anaglyph of the study area. The orthorectification procedure contributed to the achievement of the spatial resemblance (§3.3) of the compared images.

Aiming to the creation of reliable synthetic images, a very critical point of this study was the selection of the proper fusion method. The PCA method was used as the most appropriate one for the fusion of a TM with a PAN according to Yesou *et al.* (1993) and an XS with a PAN according to Tsakiri-Strati *et al.* (2002a).

The pansharpened images created through PCA contain the same quantity of information according to their entropy. They also show a significant spectral similarity according to the correlation coefficients between the corresponding bands of the compared images that were all very close to 1.0. In addition to this, the correlation coefficients calculated from combinations of two bands in each image, show that the internal relation between the bands, is kept the same in the two images.

The evaluation of their spatial accuracy similarity was accomplished through the RMS errors of their registration on the panchromatic image. The calculated RMS values which resulted the same, proved the agreement of their spatial accuracy.

One of the most important uses of a remote sensing image is the production of a land cover map and the calculation of the area of each land cover category. For this reason, it was considered of major importance, the investigation of the similarity rate between the classification products of the two synthetic images. The comparison of the two classified images took place through standard procedures, like the use of the corresponding error matrices. The derived Kappa coefficients and the calculated Z value proved that these matrices do not differ significantly statisticwise. Table 3 shows that the error matrices similarity implies similar classification products. The corresponding calculated areas of the classification categories, agree in a sufficient degree (taking into account the scale of the study).

In order the spatial agreement of the land cover categories to be examined the cross- tabulation of the two raster land cover layers were used. The confusion matrix (see table 4) of the cross tabulation showed that the corresponding land cover areas have a significant spatial agreement (87.3%).

The results of each step of this study, led to the conclusion that either of the synthetic images can be used with the same benefits for the researcher. However, it must be pinpointed that these sufficient results arise, if a careful processing of the original image precedes (i.e. orthorectification (when necessary), registration and selection of the proper fusion method).

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