LANDSAT-SPOT DIGITAL IMAGES INTEGRATION USING GEOSTATISTICAL COSIMULATION TECHNIQUES

J. Delgado[a,*], A. Soares [b], J. Carvalho [b]

[a] Cartographical, Geodetical and Photogrammetric Engineering Dept.,
University of Jaén, c/ Virgen de la Cabeza, 2 – 23071 Jaén, Spain – jdelgado@ujaen.es
[b] Environmental Group of the Centre for Modelling Petroleum Reservoirs, CMRP/IST,
Av. Rovisco Pais, 1049-001 Lisbon, Portugal – ncrmp@alfa.ist.utl.pt, jcarvalho@ist.utl.pt

KEY WORDS: Remote Sensing, Satellite, Multiresolution, Integration, Algorithms

ABSTRACT:

Interpretation of remote sensing images into terrestrial attributes is very dependent of their spatial and spectral resolution. Normally, these types of resolution are contradictory: high spatial resolution sensors have a low spectral resolution whereas multispectral sensors have a low spatial resolution. Digital image-merging procedures are techniques that aim at integrating the multispectral characteristics in a high spatial resolution image. The main objective is to obtain synthetic images that combine the advantages of the high spatial resolution and high spectral resolution of both types of images. Unfortunately, the most commonly used methods can not be considered real merging methods. They consist in a simple substitution of the high-spectral images with a high-spatial resolution image based on the correlation between both data sets. The images obtained by those merging/substitution procedures, although honouring the values of multispectral images, do not account for the spatial patterns of high spatial resolution images. In this paper a new merging approach is presented. The method is based on a geostatistical technique of direct sequential cosimulation that aims at producing images with the spatial patterns of high spatial resolution images and the local values of the coarse multispectral images. The method was applied to Landsat-TM and SPOT-P images and the results were compared with the images provided by other common merging procedures. Using the proposed geostatistical procedure, the merged images preserve the spectral characteristics of the higher-spectral resolution images in terms of both descriptive statistics and band correlation coefficients.

1. INTRODUCTION

Digital images are very frequently used in environmental and cartographic applications. Nowadays there is a wide range of systems that provide environmental and cartographic images in digital format. These images are classified according to their spatial and spectral resolution. Unfortunately, in most cases, these resolutions do not match. The high-spatial-resolution sensors have a low spectral resolution whereas the multispectral sensors have a good spectral resolution but a bad spatial resolution that limits their use in some detailed environmental applications (Figure 1).

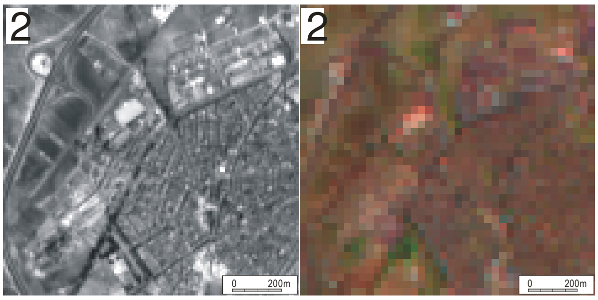

Figure 1. Left: SPOT-P image (GSD=10m),
Right: TM543 image (GSD=30m)

This problem is solved using digital image merging procedures. The main objective of these methods is to obtain synthetic images that combine the advantage of the high spatial resolution of one image with the high spectral resolution of another one. These merged images have important environmental applications like land-use, vegetation and lithological mapping, and process monitorization (for example, pollution control); applications that need to combine multispectral information with a good spectral resolution that allows the cartographical product generation at adequate scales.

Ideally, the method used to merge data sets with high-spatial resolution and high-spectral resolution should not distort the spectral characteristics of the high spectral resolution data. Not distorting the spectral characteristics is important for calibrating purposes and to ensure that targets that are spectrally separable in the original data are still separable in the merged data set (Chavez et al., 1991).

The objective of this paper is to present the results of a geostatistical merging image methodology based on direct sequential simulation. The method is used to merge the information contents of 30m Landsat-TM and 10 m SPOT-P.

2. MERGING PROCEDURES

2.1 Classical merging procedures

In order to compare results two non-geostatistical image merging methods were applied: a) Hue-Saturation-Value transformation and b) Colour Normalized.

2.1.1 Hue-Saturation-Value (HSV): HSV is one of the most often used methods to merge multisensor image data, and has been widely used to merge Landsat TM and SPOT-P data (Chavez et al., 1991). The method uses three bands of the lower spatial resolution image and transforms these data to the HSV space. The higher spatial resolution image is constantly stretched in order to adjust the mean and variance to unit intensity. The stretched image replaces the intensity component image before the images are back-transformed to the RGB space.

2.1.2 Colour normalized (CN): The colour normalized method (Vrabel, 1996) uses a mathematical combination of the colour image and high-resolution data to merge the higher spatial and higher spectral resolution images. Each band in the higher spectral image is multiplied by a ratio of the higher resolution data divided by the sum of the colour bands. The function automatically resamples the three-colour bands to the high-resolution pixel size using a nearest neighbour, bilinear, or cubic convolution technique. The output RGB images will have the pixel size of the input high-resolution data.

2.2 Geostatistical Simulation

The basic objective of this procedure is the application of geostatistical simulation techniques (direct sequential cosimulation, Soares, 2001) to obtain simulated values of the 10m Landsat TM image from the original 30m Landsat TM values and the existing correlation between the Landsat TM and SPOT P images. Here, an additional condition applies: the mean value of the 9 pixels of the 10m cosimulated Landsat TM-SPOT P image (3x3 pixels) must be equal to the 30m Landsat TM original values.

From a quantitative point of view, we intend with the simulation process to obtain a simulated image that reproduces the statistical characteristics of the merged images. The simulated image must have the same mean value as the 30m Landsat TM image and the same variance and variogram as the SPOT PAN image.

The core of the proposed merging procedure lies in the use of geostatistical simulation techniques. These techniques allow generating several realizations of the original values with a specific pixel size, preserving the basic statistical characteristic of the original images and using information derived from the high-resolution image according to the level of correlation.

Let $TM_i(x)$ be the digital value of the original 30m Landsat TM image for the band i in the pixel of position x, $PAN(x)$ the value of the original 10m SPOT-PAN image in the same position and finally, $TMsim(x)$ the digital value of the simulated 10m Landsat TM-SPOT PAN image in the position x. The simulated $TMsim(x)$ must satisfy the following requisites:

1. For any digital value ND: $\text{prob}\{TM(x)<ND\}= =\text{prob}\{TMsim(x)<ND\}$;
2. $\gamma_{PAN}(h)=\gamma_{TMsim}(h)$, where $\gamma_{PAN}(h)$ and $\gamma_{TMsim}(h)$ are the variograms of the original SPOT-PAN and simulated Landsat TM-SPOT PAN merged image, respectively;
3. Conditioning of the simulated images to the following condition: the mean of the pixels grouped according to the 3x3 pixels scheme must be equal to the 30m Landsat TM original image values.

The method used for simulation was the Direct Sequential Cosimulation procedure (Co-DSS) (Soares, 2001). One of the main advantages of this algorithm over traditional simulation methods is that it allows a joint simulation dealing directly with the original images.

The DSS algorithm is applied to simulated $TM(x)$ in a 10m grid using $TM(x)$ as primary information and $PAN(x)$ and the local correlation coefficient as secondary information and using the Markov-type approximation of the collocated cokriging method according Goovaerts (1997).

2.3 Geostatistical merging procedure

The geostatistical image merging method can be summarized in the following steps (Figure 2):

1. Calculation of the basic statistics, correlation matrix and variograms of the several images (bands) that take part in the merging process. The calculation is applied to the Landsat TM bands and SPOT-P image.

2. For each band:
    a) Generation of a sufficiently high number of cosimulated images. These images are generated using the direct cosimulation method utilizing as primary information each of the Landsat image's bands, the high-resolution image (SPOT-PAN image) as secondary information and the local correlation coefficient between Landsat TM and SPOT-P (defined in a 150x150 m window). A total of 10.000 simulated images with 10 m pixel size that integrate Landsat and SPOT-PAN information was generated for each band;
    b) Resampling the simulated images, grouping them in 30x30m size (3x3 pixels) and obtaining 30m simulated Landsat-SPOT images;
    c) For each pixel, comparison of the 30m Landsat TM original values and 30m resampled simulated Landsat-SPOT images. Three cases are possible:
        1. There is only one image where the resampled simulated images are equal to the original image. In that case, these simulated pixels are selected as definite in the final image.
        2. There are several pixels (different simulated images) that meet the previous condition. In that case, the simulated image that presents the maximum local correlation (defined in a 30 x 30 m window) between SPOT-P and Landsat-TM is selected.
        3. There is any pixel that verifies the condition. In this case, it is necessary to obtain additional images using the procedure pointed out in step 2.

3. When all of the pixels are obtained, a final checking process is carried out. The objective of this process is to locate all the pixels that present problems in the simulation. These pixels are usually pixels in which the local correlation values and SPOT-P values are very restrictive. In this case, erratic values are obtained. These values can be adjusted using a proportional coefficient that adjust the 30 m resampled simulated mean values to the corresponding Landsat image values.

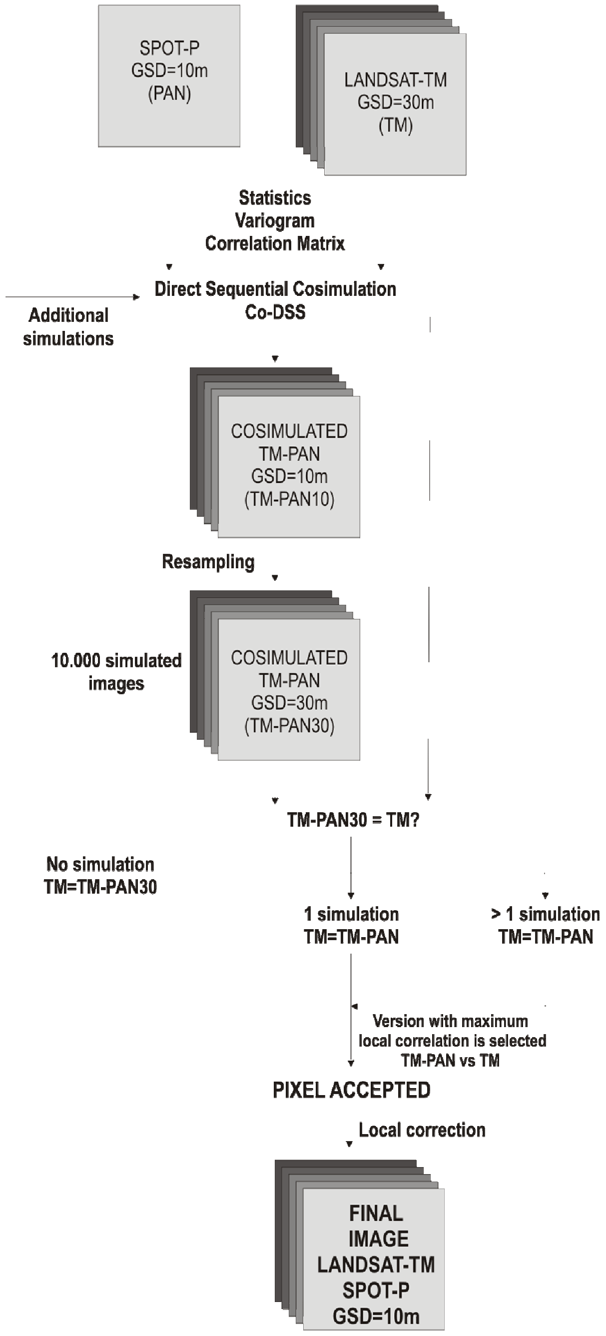

Figure 2. General schema of the proposed method

3. EXAMPLE

3.1 Geographical localization

To show the capabilities of the proposed method, a complete application example is shown. The selected zone covers a 2400mx2400m area localized in the Jaén province (S of Spain), near of Jaén city. The area presents several land-uses (urban, olive trees, riverside vegetation, roads, etc.) (Figure 3).

Figure 3. Localization map

3.2 Images

The data set used for this application is composed of a portion the following images:

1. Landsat-TM images. Scene: 20034/95. Date: 08/26/1995. Image size: 80x80 pixels. GSD=30m (TM6 band has not been considered).
2. SPOT-P image. Scene: 35-274/O-P. Date: 06/01/1995. Image size: 240x240 pixels. GSD=10m.

Both images were obtained on similar dates in order to ensure the merging process quality. In Figure 4a and Figure 4b, SPOT-P and TM543 RGB composition is shown.

3.3 Basic statistics and Correlation Matrix

The basic statistics of the different bands and matrix correlation is presented in Table 1.

Image	Mean	Std.Dev.	Minimum	Maximum
TM1	99.10	15.00	66	166
TM2	51.65	10.17	26	97
TM3	67.37	14.66	28	131
TM4	74. 99	14.37	34	133
TM5	123.56	27.62	45	226
TM7	66.67	16.77	22	139
SPOT-P	140.58	25.74	63	254

	TM1	TM2	TM3	TM4	TM5	TM7	PAN
TM1	1.00	0.96	0.90	0.84	0.85	0.81	**0.83**
TM2		1.00	0.97	0.90	0.88	0.87	**0.83**
TM3			1.00	0.91	0.89	0.90	**0.82**
TM4				1.00	0.88	0.85	**0.74**
TM5					1.00	0.97	**0.72**
TM7						1.00	**0.70**
PAN							1.00

Table 1. Basic Statistics and Correlation matrix
(PAN image is considered resampled to 30m pixel size)

It is very important to bear in mind that the correlation coefficient between the Landsat TM visible and SPOT panchromatic bands is quite high (around 0.83), but this value decreases considerably (to about 0.72) for the Landsat infrared bands.

4. RESULTS

To demonstrate the potential of the proposed methodology, the results of the application to the Landsat TM (bands 5, 4 and 3) and SPOT-PAN images are presented.

In Figure 4, the resultant images obtained from the classical methods are shown. Figure 4D shows the HSV merged image and 4E the CN merged image. In Figure 4C, the final merged image obtained from the geostatistical proposed method using the geostatistical direct cosimulation technique is presented.

First of all, we can evaluate the visual appearance of the merged images. The obtained images are markedly different. Thus the images obtained from the classical methods show a close resemblance with the SPOT-P one making the photo interpretation easier. These images have a final aspect of softly coloured SPOT images, in which the colour tones have been obtained from the Landsat TM ones.

The geostatistically merged image is more similar to the Landsat TM original images, but the visual quality of the image is better. For example, to highlight the improvement obtained with the integration, several linear features (roads) that are difficult to distinguish are labelled (labels 1 to 4) in Figure 4.

Another very interesting analysis is the statistical characteristics comparison (Table 3). In this table we can see a better conservation of statistical characteristics using the geostatistical merging procedure. In the simulation process, several conditions are applied in order to preserve these characteristics. The merged bands must have a mean similar to that of the original Landsat TM bands and their variance and variogram characteristics must be influenced by the variability characteristics of the SPOT-P image (it is important to bear in mind that the SPOT-P image is the only reference of the variability in terrain characteristics for a 10m pixel size). Also, it is very important to emphasize that this conservation is not verified for the traditional methods due to the necessary transformation that is applied previously to the merging process.

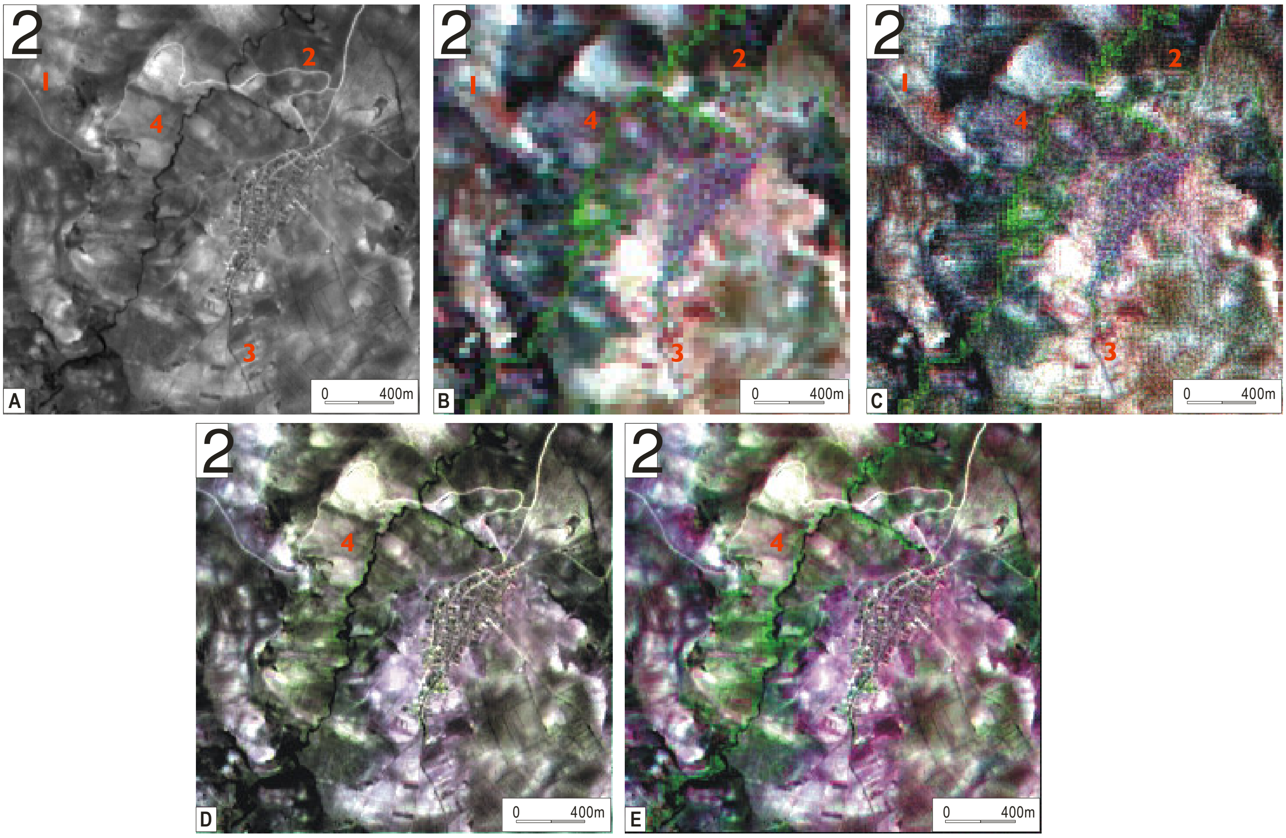

Figure 4. A: SPOT-P image; B: Landsat-TM image; C: GEOSTAT TM-PAN merged image; D: HSV TM-PAN merged image; E: CN TM-PAN image. RGB bands: 5,4,3. Linear expansion 2% (more information in the text).

	Original Landsat images (10m resampled)						PAN	HSV merged TM-PAN images (10m)					
	TM1	TM2	TM3	TM4	TM5	TM7		TM1	TM2	TM3	TM4	TM5	TM7
Mean	99.10	51.65	67.37	74.99	123.56	66.67	140.58	108.28	57.12	75.14	65.41	108.27	58.54
Std.Dev.	15.00	10.17	14.66	14.37	27.62	16.77	25.74	60.09	33.98	45.83	36.38	60.09	33.68
Min	66	26	28	34	45	22	63	0	0	0	0	0	0
Max	166	97	131	133	226	139	254	255	177	245	202	255	165

	CN merged TM-PAN images (10m)						GEOSTAT merged TM-PAN images (10m)					
	TM1	TM2	TM3	TM4	TM5	TM7	TM1	TM2	TM3	TM4	TM5	TM7
Mean	63.42	32.78	42.89	39.42	64.93	34.75	99.10	51.64	67.37	74.99	123.59	66.67
Std.Dev.	10.32	6.62	9.42	7.19	12.20	7.43	15.94	10.83	15.56	15.35	29.44	17.87
Min	31	14	17	20	27	10	66	26	28	34	45	22
Max	117	64	91	79	123	69	166	97	131	133	226	139

Table 2. Basic statistics of the merged images

	TM1	TM2	TM3	TM4	TM5	TM7	PAN
TM1	1.00	0.96	0.90	0.84	0.85	0.81	0.83
TM2		1.00	0.97	0.90	0.88	0.87	0.83
TM3			1.00	0.91	0.89	0.90	0.82
TM4				1.00	0.88	0.85	0.74
TM5					1.00	0.97	0.72
TM7						1.00	0.70
PAN							1.00

	HSV1	HSV2	HSV3	HSV4	HSV5	HSV7	PAN
HSV1	1.00	0.99	0.98	0.98	1.00	0.99	0.99
HSV2		1.00	1.00	0.98	0.99	0.99	0.99
HSV3			1.00	0.97	0.98	0.99	0.98
HSV4				1.00	0.98	0.98	0.98
HSV5					1.00	0.99	0.99
HSV7						1.00	0.99
PAN							1.00

	CN1	CN2	CN3	CN4	CN5	CN7	PAN
CN1	1.00	0.95	0.89	0.89	0.97	0.91	0.97
CN2		1.00	0.97	0.91	0.98	0.95	0.99
CN3			1.00	0.87	0.95	0.96	0.97
CN4				1.00	0.85	0.80	0.91
CN5					1.00	0.95	0.99
CN7						1.00	0.96
PAN							1.00

	Geo1	Geo2	Geo3	Geo4	Geo5	Geo7	PAN
Geo1	1.00	0.94	0.89	0.84	0.83	0.80	0.84
Geo2		1.00	0.95	0.90	0.86	0.85	0.86
Geo3			1.00	0.91	0.88	0.89	0.84
Geo4				1.00	0.88	0.85	0.78
Geo5					1.00	0.95	0.76
Geo7						1.00	0.76
PAN							1.00

Table 3. Global correlation matrix. Top: Left: Original values (10 m resampled images); Right: HSV merged images; Bottom: Left: CN merged images; Right: GEOSTAT merged images

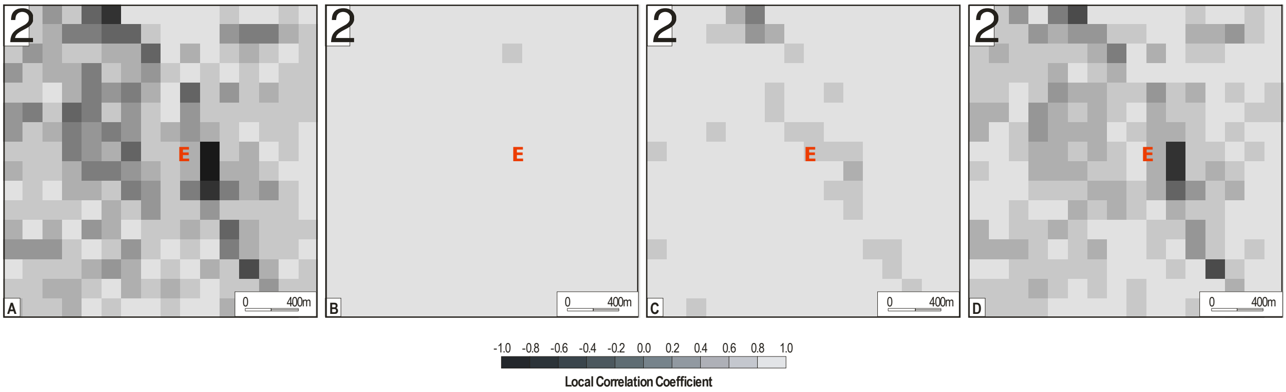

Figure 5. Local correlation values (considering a 150x150m window)
A: Landsat TM4-SPOT PAN; B: HSV-SPOT PAN; C: CN-SPOT PAN; D: Geostat-SPOT PAN (more explanation in the text)

	Mean	Std.Dev.	Minimum	Maximum	RMS	Abs.max.error
TM/PAN	0.5663	0.2903	-0.6179	+0.9210	---	---
HSV/PAN	0.9755	0.0284	+0.6749	+0.9969	0.4975	1.5898
CN/PAN	0.8963	0.1088	+0.1251	+0.9939	0.4023	1.2602
Geostat/PAN	0.6901	0.2178	-0.4061	+0.9497	0.1598	0.5063

Table 4. TM4-PAN Local correlation statistics. RMS and Absolute maximum error consider differences between local correlation coefficients of original Landsat TM4/SPOT PAN images and the merged images/SPOT PAN

HSV and CN merging methods produce an important reduction of the mean values (reaching a half of the original values for the CN method). The HSV method increases the variance values (up to three times), giving final values higher that the corresponding bands that are merged. On the contrary, the CN method produces a decrease of the variance values that is in opposition with the pixel size reduction. Finally, the Geostat method preserves the mean value of the original Landsat TM images (which is a condition imposed by the procedure) and obtains slightly higher variance values due to the reduction of the pixel size from 30m to 10m.

A basic aspect concerns the global correlation coefficients between the different images (bands) that are used in the merging process. HSV and CN methods produce a very important increase in the correlation coefficients between the merged bands and the panchromatic one. These coefficients that are around 0.82 (for visible bands) and 0.73 (for infrared bands) in the original images reach values higher than 0.97 (HSV) and 0.89 (CN). On the other hand, the proposed Geostat method preserves the original correlation values (with an increase of about 0.04-0.05 due to the influence of the SPOT-PAN image in the final merged images).

This conservation of the correlation coefficients is produced at both global and local levels. In Figure 5, TM4 vs. SPOT-P local correlation coefficients distributions, considering a 150x150m window, are shown. In the original TM-SPOT P minimum correlation values are around -0.62. This value is related to the riverside vegetation presence (label E in figure 5), which produces very high reflectance values in TM4 and very low values in the visible (panchromatic) bands (see Table 4). This behaviour is only preserved in the GEOSTAT method that presents a minimum correlation coefficient of -0.40, while the other methods always produce positive correlation coefficients.

5. CONCLUSIONS

This paper demonstrates that digital image merging through a geostatistical approach based on direct sequential cosimulation is possible. The merged images using this procedure preserve the spectral characteristics of the higher-spectral resolution images.

The visual aspect of the geostatistical-merged images is quite different from the images obtained with classical methods. The merged images produce a relevant spatial resolution improvement that makes their interpretation easier. The geostatistical methodology takes into account the global and local correlation coefficients between the images in the integration, and the coefficients are preserved. This is an important factor when it is necessary to work with non-visible spectral bands, which are poorly correlated with higher spatial resolution images that are usually panchromatic. Moreover, it is very important that the geostatistical procedure performs a real integration of the images instead of the substitution made by the classical approaches.

The main drawback of the geostatistical approach is its complexity. The method needs an important geostatistical background and suitable software. This software must be designed and optimised for large data treatment.

REFERENCES

Chavez, P.R.; Sides, S.C. and Anderson, A. (1991). Comparison of three different methods to merge multiresolution and multispectral data: Landsat and SPOT Panchromatic. *PE&RS*, 57(3), pp. 295-303.

Goovaerts, P. (1997). *Geostatistics for Natural Resources Evaluation*. Oxford University Press, New York, 483 p.

Soares, A. (2001). Direct Sequential Simulation and Cosimulation. *Math. Geology*, 33(8), pp. 911-926.

Vrabel, J. (1996). Multispectral Imagery Band Sharpening Study. *PE&RS*, 62(9), pp. 1075-1083.

ACKNOWLEDGEMENTS

This work is part of the activities of the “Sistemas Fotogramétricos y Topométricos” (Photogrammetric and Topometric Systems) research group of the University of Jaén (Andalusian Research Program). It has been partially sponsored by the grant REN2002-00079/RIES from the I+D+I program of the Spanish Ministerio de Ciencia y Tecnología, partially financed by FEDER funds of the European Union.