INTEGRATED DEM AND PAN-SHARPENED SPOT-4 IMAGE IN URBAN STUDIES

G. Doxani, A. Stamou

Dept. Cadastre, Photogrammetry and Cartography, Aristotle University of Thessaloniki, GREECE
gdoxani@hotmail.com, katerinoudi@hotmail.com

Youth Forum

ABSTRACT:

Digital orthoimages are becoming increasingly of interest as they provide up-to-date information for a wide range of applications. Facing the need for accurate spatial information this paper aims to the production of orthoimages and their further processing, as well as to the three dimensional visualization of the resulting images. The data used are one panchromatic image from Spot-3, with spatial analysis 10 m, and one multispectral from Spot-4, with spatial analysis 20 m. Both images depict the city of Thessaloniki, in Greece. In order to eliminate distortions arising from the topographic relief and improve the accuracy of orthoimages, a DTM (Digital Terrain Model) of the same area with grid size of 25 meters was used. It should be noted that the ground control points were collected by GPS measurements and two orthophotos, which were produced from 1:10,000 and 1:20,000 aerial photos. Furthermore, the panchromatic orthoimage and the multispectral orthoimage were fused with the methodology of principal components analysis. Prior to the fusion process, the registration of the image with the lower spatial analysis (the multispectral) on the image with the higher spatial analysis (the panchromatic) was necessary. In order to analyze the reliability and the accuracy of the spectral and spatial information of the synthetic image an evaluation was accomplished based on statistical tests. Additionally, supervised classification was made in the synthetic image and its accuracy was evaluated. Finally, a panoramic video was created which included a supervised flight through the area of interest for the virtual representation of the anaglyph.

1. INTRODUCTION

As the demand for digital products is getting bigger, the digital orthoimages are becoming more and more popular these days. Once the orthoimages are free from distortions arising from the topographic relief, they are more accurate and could be used diversely.

In order to eliminate geometric distortions of the images obtained by satellites is essential to alter their geometric form. This is accomplished through the process of geometric correction by using one geometric model, in this case the Spot geometric model. The result is the registered digital image. Subsequently, the resampling of the registered image, which calculates the new pixel values with the method of bicubic interpolation, is necessary for the production of the orthoimage. After this procedure the central perspective image is transformed into an orthogonal projection.

To broaden the uses of orthoimages with different radiometric, geometric and spectral characteristics, is important to fuse all this information and produce a synthetic image. A synthetic image combines the spatial resolution of the high spatial analysis image and the spectral resolution of the one with the high spectral analysis. Its characteristics make possible the full exploitation of the image data.

Additionally, from the classical cartographic point of view, is considered essential the classification of the image pixels into different types of classes, representing specific kinds of land. The result of this procedure is a thematic map, which provides useful information. In this paper, with the method of supervised classification, the types of classes were determined from the beginning, choosing the 7 most important land cover and use of the area of interest.

Finally the 2D and 3D image data are elaborated with a view to produce various forms of visualization.

2. DATA

The used data are one panchromatic image from Spot-3, with spatial analysis 10 m and one multispectral from Spot-4, with spatial analysis 20 m. Both images depict the city of Thessaloniki, in Greece. Also a DTM (Digital Terrain Model) of the same area with grid size of 25 meters is used.

Ground control points collected by GPS measurements and two orthophotos, which were produced from 1:10,000 and 1:20,000 aerial photos.

For the development of this paper is used the software of the Erdas Imagine 8.5.
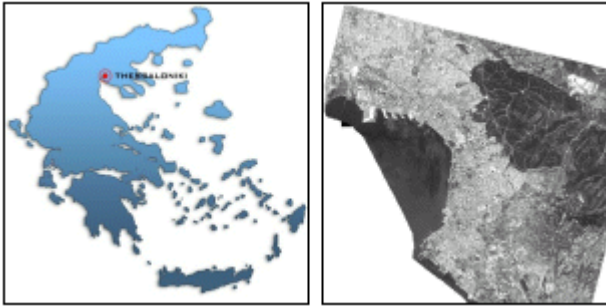
Figure 1. The study-area of Thessaloniki, Greece

3. ORTHORECTIFICATION

As it is mentioned above, through the process of orthorectification the two Spot images, the panchromatic and the multispectral, are transformed into an orthogonal projection, which makes them as accurate as a map in the same scale. This is accomplished through the following procedures.

3.1 Geometric model and projection

The accurate geometric model, taking into account the geometry of the acquisition and by recovering the distortions that exist describes the relation between the sensor and one ground reference system. In classic Photogrammetry this relation between camera, image and ground is described by the collinearity equations. This cannot be applied in remote sensing because the elements of the exterior orientation are not stable. This is due to the great speed of the satellite and the long time of acquisition.

In the case of the spot geometric model, it is considered that the satellite has steady movement during the time of the 9 seconds (duration of the acquisition of one spot image) and one scanning line is defined as a reference line. This can be the first or the central line. In this way, and as the exterior orientation of the reference line has been defined; the exterior orientation of all the rest lines is also determined, based on the distance between them, the changes of the position of the project center and the rotation angles.

The mathematical spot model is a broaden model of collinearity equations with a difference that the satellite's route is steady during the acquisition time so its movement can be modelled with a polynomial of 1st and 2nd grade. The exterior orientation in a polynomial of 1st grade includes 6 parameters that describes the route (position and speed),

$$X(t) = X_o + X't \qquad (1)$$
$$Y(t) = X_o + Y't \qquad (2)$$
$$Z(t) = Z_o + Z't \qquad (3)$$

where X_0, Y_0, Z_0 = coordinates of projection center of reference line

X', Y', Z' = velocities in each direction

and 6 parameters that describe the satellite orientation,

$$\omega(t) = \omega_o + \omega't \qquad (4)$$

$$\varphi(t) = \varphi_o + \varphi't \qquad (5)$$
$$\kappa(t) = \kappa_o + \kappa't \qquad (6)$$

where $\omega_o, \varphi_o, \kappa_o$ = 3 rotation angles

$\omega', \varphi', \kappa'$ = their change rates

The result is a model that has 12 unknown parameters and the time as an independent variable for the 6000 lines of a spot image.

The Erdas IMAGINE has the option of choosing this geometric model during the process of the orthorectification.

As far as the projection is concerned, the EGSA'87 is chosen, because this one is the official projection of Greece.

3.2 DTM (Digital Terrain Model)

The integration of DTM into the two images is the most crucial part of the orthorectification process, as its role is to eliminate the relief displacement. Moreover the DTM quality affects the accuracy of planimetry in orthophotos. The DTM that is used is a mosaic of two different DTMs in order to succeed the utmost accuracy. Both of them were produced with photogrammetric proceedings from aerial photos of scale 1:10000 and 1:20000.The grid size is 25 meters.

3.3 Control points

The role of the ground control points (GCPs) is to define the exterior orientation elements of one image. Their accuracy is of a great importance because affects the accuracy of the orthoimage. Except for their high accuracy, it is recommendable that they have good geometry. This means that they should have symmetric position over the image and cover the whole area of interest.

At this point it should be mentioned that the ground control points in this project were obtained from GPS measurements and from other existing orthoimages that depict the same area. For this reason they have different accuracy.

For the rectification of the panchromatic image, 57 control and 15 check points were used, and for the multispectral 61 control and 15 check points.

3.4 Resampling

Most geometric transformations lead to pixels that do not coincide with the original image. Resampling is the process of calculating the intensity of the new pixels with one method of interpolation. The data values for the pixels are interpolated on the new grid from the values of the source pixels, an invaluable procedure in the generation of an orthoimage.

In Erdas IMAGINE the following methods of interpolation are supported:
1. **Nearest neighbour**: uses the value of the closest pixel to assign to the output pixel value
2. **Bilinear interpolation**: uses the data file values of four pixels in 2 x 2 window to calculate an output value with a bilinear function
3. **Bicubic interpolation**: uses the data file values of sixteen pixels in 4 x 4 window to calculate an output value with a bicubic function

In this project, Bicubic interpolation is selected, because this method sharpens the image and smoothes out noise and simultaneously the loss of image information is eliminated.

3.5 Results

The expected results of the process of rectification should be near to sub pixel and this is achieved in this project, as it is shown to the below tables:

	X residual (pixel)	Y residual (pixel)	RMS Error (pixel)
Control Point	0,6166	0,6503	0,8962
Check Point	0,5944	0,6139	0,8545

Table 2. The rectification results of the panchromatic image

	X residual (pixel)	Y residual (pixel)	RMS Error (pixel)
Control Point	0,7526	0,4541	0,8450
Check Point	0,7835	0,4715	0,9145

Table 3. The rectification results of the multispectral image

3.6 Check of the produced orthoimages

Finally, the resulted two orthoimages are tested in order to assess their accuracy, by measuring and comparing the image coordinates of control points to the known coordinates of the available orthophotos. The chosen 20 points are well distributed all over the area. The standard deviation is 8,9m for the panchromatic image and 4,7m for the multispectral.

4. FUSION

It is often desirable to simultaneously require high spatial and spectral analysis in a single image. This is accomplished with the process of fusion. Fusion combines data from different sensors with dissimilar resolution and provides images with increased interpretation capabilities.

The images have to be rectified in the same reference system, cover the exactly same area and have the same dimensions (the same number of pixels / row and pixels / column), in order to be fused. Firstly, it is necessary to registrate the low-resolution image on the high-resolution image, so as to be possible to compare these two images pixel by pixel. Moreover, it is essential that the images have been orthorectified for the more accurate pixel-by-pixel corresponding, especially in the case of mountainous areas.

4.1 Preparation of the images

First of all the low-resolution orthorectified image is registered to the high-resolution orthorectified image, for the absolute coincidence of pixels. It is also necessary to define the exact area of study in the two images; with view to obtain the corner pixels of the two images the exact same cartographic coordinates.

After these preparations the two images are ready to be fused with the principal components analysis (PCA).

4.2 The principal components analysis (PCA)

In fusion with the PCA technique, the new band PC1 can be replaced by the panchromatic. This is possible because they are considered to have the same spectral characteristics. By inversion of the new principal components the result is one synthetic image, which maintains the spatial characteristics of the panchromatic image, and at the same time has the spectral information of the multispectral. That is a synthetic image with spatial resolution 10m.
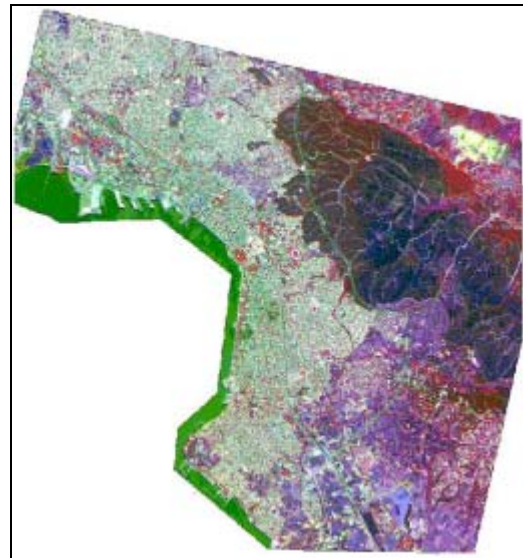

Figure 4. The synthetic image

4.3 Evaluation of the spectral and spatial quality of the synthetic image

In order to be more reliable and useful the synthetic image it is important to valuate its spectral and spatial quality. The comparison of the synthetic image to original multispectral is accomplished under some certain conditions. The two compared images must have the same spatial analysis and their spectral information must be identical. That's why the synthetic image should be degraded to the analysis of the original multispectral, and the all band histograms of the synthetic image must be matched with the histograms of the original multispectral image.

For the spectral quality the following criteria are used:

1. Standard deviation, mean, correlation coefficient (Wald et.al., 1997).
2. The NDVI index (Tsakiri, 2001)

Comparison between multispectral – synthetic image				
	Band 1	Band 2	Band 3	Band4
Bias (ideal value: 0)	0.178	0.099	0.079	0.016
Correlation coefficient (ideal value: 1)	0.798	0.804	0.814	0.747
Standard deviation of the difference image (ideal value: 0)	0.296	0.007	0.03	0.039
Comparison between NDVI multispectral – NDVI synthetic image				
Bias (ideal value: 0)	1.143			
Correlation coefficient (ideal value: 1)	0.931			
Standard deviation of the difference image (ideal value: 0)	2.611			

Table 5. The results of the statistical tests

The spatial evaluation of the synthetic image is done in order to detect if the synthetic image maintains the spatial characteristics of the high-resolution image (panchromatic image). A high pass filter 7x7 is applied over the synthetic and orthorectified panchromatic image, with the view to exaggerate the linear characteristics. The correlation between the images is done, after the matching of the 'high-pass' synthetic to the 'high-pass' panchromatic image histograms.

Correlation coefficient between 'high-pass' panchromatic – 'high-pass' synthetic image				
	Synthetic BANDS			
	1	*2*	*3*	*4*
Panchromatic BAND	0.892	0.863	0.85	0.834

Table 6. The results of the correlation between 'high-pass' panchromatic – 'high-pass' synthetic image

5. CLASSIFICATION

The relevant data derived from the satellite sensors are so many that the classical interpretation methods for the extraction of information are difficult and time-consuming. Classification is one of the most reliable methods of recording pixels in classes of land use, with multispectral classification.

Classification is the process of defining the image pixels into various classes, representing the different types of land cover and use. Each class or category in one image represents a group of pixels that have the same spectral values.

There are two kinds of classification: **1) the unsupervised classification**, where the classes of pixels are determined according to their band values without the use of the external data. Once the pixel classes have been formed the land cover type of each class is identified with the help of pixels within the class whose land type has been determined by fieldwork. **2) the supervised classification**, where the pixels with known land cover type, determined by fieldwork form the nuclei for the classification of the remaining pixels in one of the already identified classes, on the basis of their band values. (*A.Dermanis: Remote sensing*)

5.1 Preparation of the image

In this project the supervised classification is applied on the synthetic image, which was produced with the process of fusion. It should be noted that the synthetic image was divided into two parts, the one of the urban and the other of the hilly area. Each part is classified separately. This is done, because otherwise there were problems in the exact definition of the classes, and so the correlation between pixels and classes was not right and accurate.

5.2 The steps of the classification

The first and most important step in the process of classification is the definition of all the classes, where the pixels are going to be inscribed. Consequently, the choice of the samples from specific parts of the image must be done carefully, for the right correlation between the pixels and the classes.

For the first part of the synthetic image, the urban area, the following classes are chosen:

1. Trees
2. Grass
3. Concrete
4. Buildings
5. Ground
6. Ring road

For the second part of the synthetic image, the hilly area, the following classes are chosen:

1. Forest
2. Burnt forest
3. Road

By collecting the proper samples of each class, the classification is realised according to the fuzzy logic, which contributes to better results.
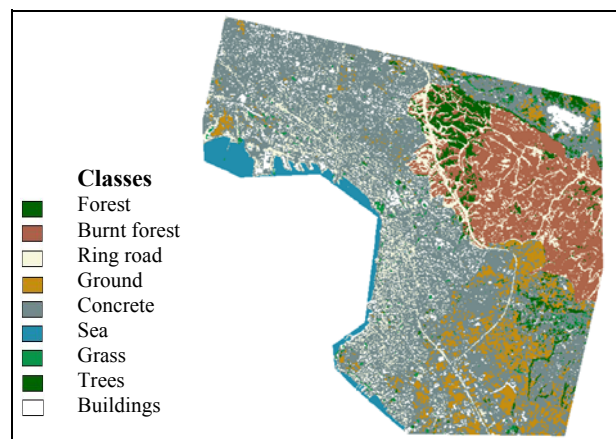

Figure 7. The classified image

5.3 Evaluation of the classification's accuracy

Comparing some specific pixels of the classified image and their corresponding reference pixels, which belong to a known class, succeeds the evaluation of the classification.

The results of this comparison are the error matrix, the accuracy totals and the kappa statistics.

Accuracy results for the urban image part

ERROR MATRIX

Classes	Grass	Ground	Sea	Concrete	Buildings	Ring road	Trees
Grass	7	0	0	0	0	0	0
Ground	0	8	0	0	0	0	0
Sea	0	8	8	0	0	0	0
Concrete	0	1	1	5	0	0	0
Buildings	0	0	0	0	8	1	0
Ring road	0	1	0	2	1	0	1
Trees	0	1	0	0	0	3	7
Total test pixels	7	11	9	7	9	4	8
Overall Accuracy	83.64%			**Kappa coefficient:** 0.8090			

Table 8. The accuracy totals and the kappa statistics for the urban area

Accuracy results for the hilly image part

ERROR MATRIX

Classes	Forest	Burnt forest	Streets
Forest	9	0	0
Burnt forest	0	8	1
Streets	1	3	5
Total test pixels	10	11	6
Overall Accuracy	81.48%	**Kappa coefficient**:0.7222	

Table 9. The accuracy totals and the kappa statistics for the hilly area

6. VISUALIZATION

Recent satellite images, as it is known, can provide not only more, but also more accurate information. Moreover, 2D and 3D maps, as well as virtual flights, are more updated and accurate than the classical traditional maps.

6.1 Visualization of DTM

The process of DTM is realised, in order to obtain different ways of relief restoration. The produced images are:
  a) **Shaded relief**, in this monochromatic image the differences of elevation are exaggerated and the slope of ground is clearly shown
  b) **Slope,** in this image the slopes of anaglyph are illustrated
  c) **Aspect,** the slopes in this case are restored according to the values of azimuth
  d) **Painted relief,** in this multicolour image, the different layers of elevation are restored with gradations of colours
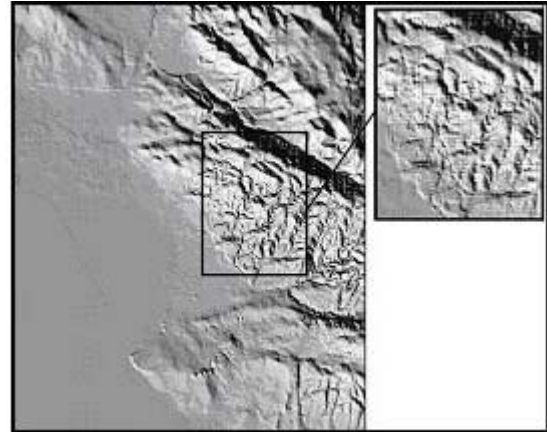

Figure 10. The shaded relief image

6.2 Visualization of synthetic image

The result of this process is a new image that represents better the angles, the figures etc. and generally the spatial characteristics of the synthetic image.
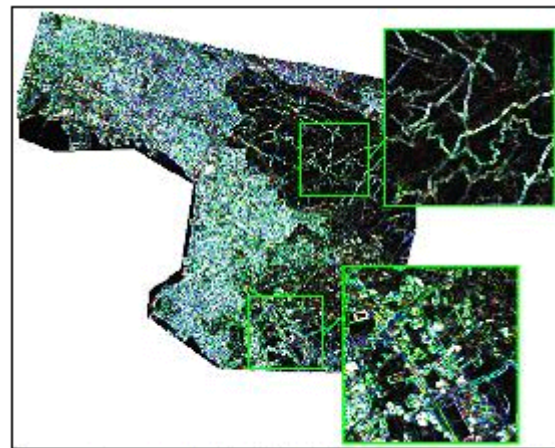

Figure 11. The texture of the synthetic image

The 3D video shows a flight over the synthetic image draped on the DTM. The low resolution of the image and the smooth anaglyph affects the discrimination of the urban area and so the flight is more interesting over the hilly area.

Figure 12. The route of the 3D video-flight

7. CONCLUSIONS

In this project, the images that have been orthorectified are spot images, with spatial analysis 10m the panchromatic and 20m the multispectral. The problem during the orthorectification was the exact location of the control points in the images due to their low analysis. Finally the resolution of the panchromatic orthoimage is 8,9m and of the multispectral is 4,9m.

The synthetic image maintains the spectral and spatial characteristics of the initial orthoimages, as the statistical tests demonstrate.

As for the classification, the statistic tests that were done led to very satisfactory results, 83,64% for the urban area and 81,48% for the hilly area.

The results of visualization give one very realistic representation of the anaglyph, especially for the hilly area because the urban area has smooth anaglyph. The elevation differences are clearly attributed and shown, by the visualization of the DTM and the 3D flight-video over the area of interest.

8. REFERENCES

Amhar, F., 1998. The generation of true orthophotos using a 3D building model in conjunction with a conventional DTM. In: *The International Archives of the Photogrammetry and Remote Sensing*, Stuttgart, Germany, Vol. 32, Part 4, pp. 16-22.

Behdinian, B., 2002. Generating orthoimage from Ikonos data. Publication in session "Very high resolution mapping" in 23rd Asian Conference on Remote Sensing, Kathmandu, Nepal. http://www.gisdevelopment.net/aars/acrs/2002/vhr/017.pdf (accessed 2 Oct. 2003)

Dermanis, A., 2002. *Telerilevamento*. Zanichelli, Milano, pp. 163-172.

Erdas, 1999. *Erdas Field Guide*, Erdas 5th ed., USA, pp. 226-236, 279-288, 357-364.

Kratky, V., 1989. Rigorous photogrammetric processing of SPOT images at CCM Canada. *ISPRS Journal of Photogrammetry and Remote Sensing*, No. 44, pp. 53-71.

Li, J., 2000. Spatial quality evaluation of fusion of different resolution images. In: *The International Archives of Photogrammetry and Remote Sensing*, Amsterdam, Netherlands, Vol. XXXIII, Part B7, pp. 752-759.

Pohl, C., Van, G.J.L., 1998. Multisensor Image Fusion in Remote Sensing: Concepts, Methods and Applications. *International Journal Remote Sensing*, Vol. 19, No. 5, pp. 823-854.

Schickler, W., Thorpe, A., 1998. Operational procedure for automatic true orthophoto generation. In: *The International Archives of the Photogrammetry and Remote Sensing*, Stuttgart, Germany, Vol. 32, Part 4, pp. 527-532.

Tsakiri-Strati, M., Papadopoulou, M., Georgoula, O., 2002. Fusion of XS SPOT4 and PAN SPOT2 images and assessment of the spectral quality of the products. *Technika Chronika,*

Scientific Journal of the Technical Chamber of Greece, Section A, vol. 22, No. 3.

Wald, L., Ranchin, T., Mangolini, M., 1997. Fusion of satellite images of different spatial resolutions: Assessing the quality of resulting images. *Photogrammetric Engineering & Remote Sensing,* Vol. 63, No. 6, pp. 691-699.

Yesou, H., Besnus, Y., Rolet, J., 1993. Extraction of Spectral Information from Landsat TM Data and Merger with SPOT Panchromatic Imagery- A Contribution to the Study of Geological Structures. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 48, No. 5, pp. 23-36.

Zhang, Y., 2001. Texture-Integrated Classification of Urban Treed Areas in High-Resolution Color-Infrared Imagery. *Photogrammetric Engineering & Remote Sensing*, Vol. 67, No. 12, pp. 1359-1365.

Zhang, J., Foody, G.M., 1998. A fuzzy classification of sub-urban land cover from remotely sensed imagery. *International Journal Remote Sensing*, Vol. 19, No. 14, pp. 2721-2738.