URBAN ORTHOIMAGE ANALYSIS GENERATED FROM IKONOS DATA

S. Siachalou

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

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ABSTRACT:

Due to the increasing demand and use of digital spatial information, the interest is being drawn to the generation of digital orthophotos, which is the most accurate and reliable source of spatial information. The subject of this project is the generation of orthoimages as well as the further processing of these orthoimages for the full exploitation of their spectral and spatial information. The imagery data used are a panchromatic image of one-meter spatial resolution and a multispectral image of four-meter spatial resolution, both acquired from Ikonos-2 satellite over the extended region of the city of Thessaloniki. The orthorectification of the images involved the establishment of the interior and exterior orientation through the Rational Function coefficients, a number of ground control points, and a Digital Terrain Model (DTM). Following the orthorectification, the panchromatic orthoimage was fused with the multispectral orthoimage to produce a pan-sharpened image with the method Principal Components Transformation. At this point the spectral quality and the spatial accuracy of the pan-sharpened image were assessed by certain criteria, as it is very significant for the sharpened image to maintain the spectral and the spatial information of the original data. In order to produce an image containing thematic information a supervised classification pan-sharpened was realised. Finally the products of the analysis of the pan-sharpened orthoimage were used for the visualization of the study area.

1. INTRODUCTION

Since the launch of Ikonos satellite a new era for Remote Sensing products has began. The generation of high-resolution orthoimages is an important task as it has a use in various applications such as mapping, agriculture and urban planning. Thus it is of great importance to produce digital spatial products and improve their geopositional accuracy. In this project the improvement of the accuracy of the orthoimages was accomplished by the use of GCPs obtained by GPS measurements and orthophotos, a DTM and Ikonos images. Since the camera model and precise satellite ephemeris data are not available for Ikonos imagery, the use of the Rational Function was decided as it can offer a very accurate approximation to the rigorous physical sensor model (Kratky, 1989).

Furthermore the applications mentioned require further processing of the orthoimages in order to extract all the useful information. Having this in mind, the panchromatic orthoimage was fused with the multispectral orthoimage so as to achieve high spatial resolution while maintaining the provided spectral resolution,. It should be noted that the synthetic orthoimage is ideal for the extraction of thematic information, which can be made though classification.

2. DATA

The satellite data used is a panchromatic Ikonos image of 1-m resolution and a multispectral Ikonos image of 4-m resolution both over the extended region of the city of Thessaloniki. For the orthorectification of these images two DTMs were available, the first one has a grid size of 25-m and covers all the study area while the second one has a grid size of 20- m and covers the hilly region of Seih Sou. The GCPs used were obtained by GPS measurements and orthophotos of scale 1: 5000.

The software used for the processing of the data is Erdas IMAGINE 8.5.

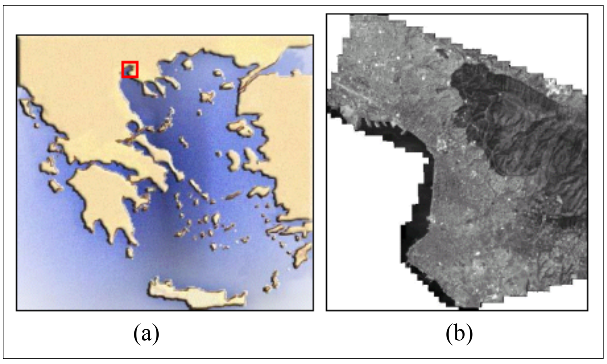


Figure 1. a) Map of Greece with the area of interest b) the panchromatic Ikonos image

3. ORTHORECTIFICATION

3.1 Geometric Sensor Models

Sensor models are vital in orthorectification because they describe the relationship between the coordinates of the image space and the object space and allow their transformation. There are two categories of sensor models, the physical and the generalised models. The physical sensor model establishes the physical imaging process. This can be a disadvantage because the position and orientation of a satellite sensor changes during the image acquisition, the geometric model is time-dependent and is therefore very complex and time-consuming. Another disadvantage is that for every sensor type different model and different processing software has to be established. These reasons motivated the replacement of the physical sensor models by generalised models (Tao and Hu, 2001).

In 1989 Kratky suggested as a generalised model the use of polynomial Rational Functions that can support real time implementations and provide accurate solutions. The Rational Function model transforms the image pixel coordinates through the ratios of polynomial of ground coordinates. In this project Space Imaging Inc. provided the Rational Function coefficients (RFCs) used in the orthorectification process.

3.2 The orthorectification processing

Firstly the following input data were used to perform the orthorectification:

- The RFCs provided by Space Imaging Inc.
- The DTM that has a grid size of 25-m and covers all the study area
- The GCPs obtained by GPS measurements and additional GCPs obtained by orthophotos of scale 1: 5000 in order to cover evenly all the study area

The orthorectification with these data resulted in a large RMS error of about 35 m. Aiming to minimise this error a methodology was developed involving the following tasks:

- Synthesis from the two existing DTMs of a more accurate DTM
- Refinement of the RFCs according to the ground coordinates of the GCPs
- Orthorectification separately in three parts of the image (the west, the east part of the city and the hilly region)

3.2.1 Synthesis of DTM: In order to improve the accuracy of the DTM within all the study area the existing DTMs were mosaicked. Taking into account that the orthorectification of areas with intense anaglyph is usually problematic, it was considered necessary to use a highly accurate DTM in the hilly region. Thus in this specific part of the image it was preferable to use the DTM which covers this specific region and is characterized by a better accuracy.

The process of mosaicking the DTMs consisted of three tasks. Initially, the hilly part was extracted from the DTM that covers all the study area. The extraction was made to the base of the mountain along points that were found to have about the same elevation in both DTMs. The second task involved changing the grid-size of the DTM of the hilly part (20 m) to fit the grid-size of the other DTM (25 m) through the process of resampling. It was also necessary to cut the DTM of the hilly part near the points mentioned above, so as to have a small overlapping with the other DTM. Finally, the DTMs were mosaicked and as for the overlapping area it was chosen to take the elevation values from the DTM of the hilly part, with the better accuracy.

3.2.2 Refinement of the RFCs: The vendor-provided RF coefficients can be improved to provide a more accurate solution. Based on the known coordinates of the GCPs an affine transformation can be applied using as initial values the vendor-provided RFCs (Di et al., 2003).

3.2.3 Orthorectification in three parts of the image: The orthorectification processing was applied three times for three parts of the image. Due to the fact that images with an intense anaglyph demand special attention during their orthorectification, it was preferable to process the hilly part separately. In order to have a good distribution of GCPs the image was also processed separately as far as the west and the east part were concerned.

In this way three orthorectified image parts were produced which were finally joined together through mosaicking. The same methodology was carried out for both the panchromatic and the multispectral image and led to an improved accuracy of about 3.5 m.

Image parts	No.		RMS	
	Control	Check	Control	Check
West part	23	10	3.7 m	3.1 m
East part	51	15	3.9 m	3.7 m
Hilly part	29	10	2.9 m	2.9 m

Table 2. The number of points and RMS errors of the orthorectification of each part of the image

3.3 The results of the orthorectification

There are many factors that can influence the orthorectification processing and reduce the accuracy of the orthoimages. In this case the reasons can be found in the insufficient accuracy of the initial DTM, of the vendor-provided RFCs or in the different sources of GCPs (GPS and orthophotos). Using the methodology mentioned helped facing these problems and minimized the RMS error to a sufficient extend.

In Table 3 the results of the orthorectification are listed according to the data being used and the great improvement of the accuracy is shown.

Image	DTM	RFCs	RMS
Whole image	Initial DTM	Before the refinement	35 m
Whole image	Synthetic DTM	After the refinement	10 m
Three parts of the image	Synthetic DTM	After the refinement	3.5 m

Table 3. RMS errors of the orthorectification according to the data used

4. FUSION

4.1 The fusion of images

In 1999 Wald defined data fusion as a formal framework that expresses the means and tools for the alliance of data originating from different sources; it aims at obtaining information of greater quality; the exact definition of "greater quality" will depend upon the application. Image fusion aims at the generation of a single image from multiple image data for the extraction of information of higher quality (Pohl, 1999).

Within this framework this project focused on a type of image fusion, the image sharpening. In image sharpening, higher spatial resolution panchromatic data is fused with lower spatial resolution multispectral imagery. This means that a pan-sharpened image combines the spatial and spectral characteristics of both images. Many algorithms and techniques have been developed to sharpen imagery successfully, among which the Principle Components Transformation was selected.

4.2 The preprocessing of the images

The images to-be fused should fulfill some conditions, to be projected to the same coordinate system and to cover exactly the same area. Although in this case the images to-be fused were orthorectified it is also necessary to co-register the multispectral to the panchromatic orthoimage. Only with the co-registration of the low-resolution image to the high-resolution image an absolute correspondence of the pixels with the same coordinates is accomplished.

Additionally, the images to-be fused should have a radiometric correlation between them. For this reason before the fusion, a matching of the histogram of the panchromatic orthoimage to the histogram of the multispectral orthoimage is essential. This process guaranties that the two images have the same contrast and brightness.

4.3 Fusion with the Principal Components Transformation

The Principal Components Transformation (PCT) is a commonly used algorithm for the fusion of imagery. It calculates the principal components of the multispectral image and transforms the set of bands into pseudo-bands with the same total, but a different distribution of variance. The first principal component represents the largest variance, is considered to resemble spectrally the panchromatic band and thus it can be replaced by it. From the new PC image through a PC-inversion the pan-sharpened image is generated.

Figure 4. The pan-sharpened image

4.4 Evaluation of the spectral quality of the pan-sharpened image

Evaluating the spectral quality of the result of the fusion is a very important process. The pan-sharpened image should preserve the spectral characteristics of the images that were produced. This involves a spectral comparison between the pan-sharpened image and the multispectral orthoimage.

In order to be able to compare these images they should have the same resolution. The 1-m pan-sharpened image was degraded to 4-m. Apart from this it was essential to implement a histogram matching of the pan-sharpened image to the multispectral orthoimage so as to be radiometrically similar.

To assess the spectral quality of the pan-sharpened image certain criteria were used:

- The bias, which is the difference between the means of the original multispectral orthoimage and the pan-sharpened image. Ideally, the bias should be null.
- The correlation coefficient between the original image and the pan-sharpened image. It shows the similarity in small sizes structure between the two images. It should be as close as possible to 1.
- The standard deviation of the difference image, which globally indicates the level of error at any pixel. Ideally, it should be null (Wald et al., 1997).
- The NDVI index was applied to both images, which detects vegetated areas. The original and the pan-sharpened image images should have the same spectral reaction to the specific index meaning that the NDVI images should spectrally similar. Thus the bias, the standard deviation and the correlation coefficient between the NDVI images were computed (Tsakiri et al., 2002).

The criteria for the evaluation are presented in Table 5. From this table it can be indicated that the pan-sharpened image preserves to a satisfactory degree the spectral information of the multispectral orthoimage.

Comparison between multispectral – pan-sharpened image				
BANDS:	*1*	*2*	*3*	*4*
Bias (ideal value: 0)	3.16	1.96	1.66	0.73
Correlation coefficient (ideal value: 1)	0.82	0.84	0.85	0.83
Standard deviation of the difference image (ideal value: 0)	21.37	19.59	18.70	16.39
Comparison between NDVI multispectral – NDVI pan-sharpened image				
Bias (ideal value: 0)	2.38			
Correlation coefficient (ideal value: 1)	0.91			
Standard deviation of the difference image (ideal value: 0)	6.40			

Table 5. Criteria on the spectral evaluation of the pan-sharpened image

4.5 Evaluation of the spatial quality of the pan-sharpened image

During the production of the pan-sharpened image another concern is the quality of the spatial information. The pan-sharpened image should maintain the spatial characteristics of the initial panchromatic orthoimage and assure this, a certain assessment of the pan-sharpened image is performed.

The methodology used presupposes the application of a high-pass filter (Zhou et. al., 1998; Li, 2000). It is known that a high-pass filter enhances the edges between homogenous groups of pixels and increases the spatial frequency of an image. In this case, a 7×7 high-pass filter is applied to the initial panchromatic orthoimage and the pan-sharpened image. Before the comparison of the two 'high-pass' images a histogram matching of the pan-sharpened image to the panchromatic orthoimage was indispensable.

In Table 6 the correlation coefficients between the panchromatic band the pan-sharpened bands are presented. Given that the ideal value is 1, it can be noted that the pan-sharpened image preserves the characteristics of the initial high-resolution image it came from.

Correlation coefficient between 'high-pass' panchromatic – 'high-pass' pan-sharpened image				
	Pan-sharpened BANDS			
	1	*2*	*3*	*4*
Panchromatic BAND	0.99	0.99	0.99	0.99

Table 6. Criteria on the spatial evaluation of the pan-sharpened image

5. CLASSIFICATION

Having a pan-sharpened image of good spectral and spatial quality enables us to derive reliable thematic information through the process of classification. Classification of urban environment plays a key role in Urban Area Land-use Mapping, Urban Planning and Management, Establishment and Revision of GIS Database, Environment and Disaster Monitoring and Establishment of Telecommunication Network Station (Yu et al., 2002). With the development of high-resolution satellites it is now possible to collect and map thematic information from images of urban areas on large scales. However, high-resolution data does not mean high classification accuracy. In such cases, classification is more difficult due to the heterogeneity of urban structures.

5.1 The procedure of classification

At first, a supervised classification with the method of maximum-likelihood classification was applied to the pan-sharpened image. Although a careful and detailed training was carried out, problems arose during the evaluation of the samples. Specifically, in the resulting classified image some streets were mixed up with buildings and territories of bare soil were misclassified as burnt forest.

For this reason a different approach was decided. In urban areas roofs, streets and pavements are built of a similar material, so their similar reflectance creates problems during the classification process. The pan-sharpened image was separated to the urban part and the hilly tree-covered part and the classification was applied to these two image parts.

Firstly, the set of classes was selected for each part and consists of streets, roofs, tiles, bare soil, low vegetation, trees and shadow for the urban part and trees, burnt forest, streets and rural streets for the hilly part. After the selection of the samples for each class, they were assessed through their histograms and the diagrams of their means and found to be representative and satisfactory.

A fuzzy classification was introduced for both image parts and a distance file was created. The fuzzy approach was preferred because it allows more information on the partial class membership to be made available. The classified images were chosen to have two layers of which Layer 1 contains class values for the best classification, Layer 2 for the second best. The pixels of the distance file consist of the values of the distance of the class means. With the help of the classified images and the distance files the Fuzzy Convolution operator creates a single classification layer by calculating the total weighted inverse distance of all the classes in a window of pixels, in this case a 3×3. Then it assigns the center pixel in the class with the largest total weighted inverse distance over both fuzzy classification layers. This reduces the phenomenon of 'salt and pepper' in the classified image which the mixed pixels produce (Erdas, 1999). The final classified image is presented in Figure 7.

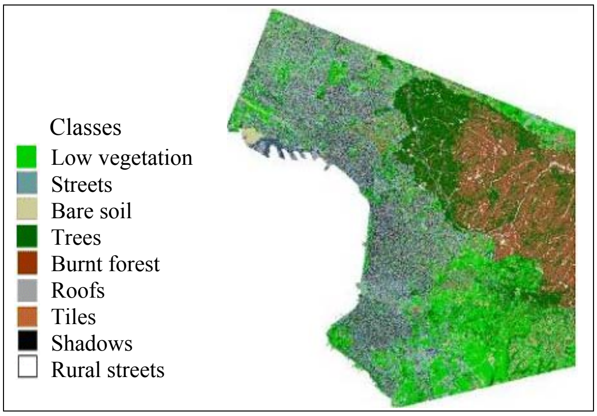


Figure 7. The classified image resulted from the application of the supervised classification

5.2 Accuracy assessment of the classification

The procedure of classification is completed when its accuracy is estimated. The error of the classification, which expresses the misclassification of some pixels, determines the degree of success of the procedure. For this reason a comparison is made between classified data and ground reference data and the error matrix, the accuracy report and the Kappa coefficient are calculated. The results are presented in Table 4.

ACCURACY RESULTS FOR THE URBAN IMAGE PART							
ERROR MATRIX							
Classes	Low veg.	Streets	Bare soil	Trees	Shadows	Roofs	Tiles
Low veg.	0	1	1	0	1	0	0
Streets	7	8	0	0	1	1	0
Bare soil	0	0	8	0	0	1	1
Trees	0	0	0	10	0	0	0
Shadows	0	0	0	0	10	0	0
Roofs	0	2	0	0	2	6	0
Tiles	0	0	1	0	1	0	8
Total test pixels	7	11	10	10	15	8	9
Overall Accuracy = 84.43%				Kappa coefficient = 78.33%			

ACCURACY RESULTS FOR THE HILLY IMAGE PART				
ERROR MATRIX				
Classes	Trees	Burnt forest	Streets	Rural streets
Trees	6	2	0	0
Burnt forest	0	8	0	0
Streets	1	0	5	2
Rural streets	0	1	0	7
Total test pixels	7	11	5	9
Overall Accuracy = 81.25%			Kappa coefficient = 75.00%	

Table 8. The error matrix, the overall accuracy and the kappa coefficient of the two classified image parts

Given that the ideal value for the overall accuracy is less than 70-75% and for the Kappa coefficient less than 75% it should be noted that the classification has a high accuracy (Overall Accuracy of 84.43% and 81.25% and Kappa coefficient of 78.33% and 75.00% for each case).

6. VISUALIZATION

The interest in observing the environment was the motive for the development of the visualization of 3D objects. Visualization aims at examining the earth's surface with perspective by combining remotely sensed data and Digital Terrain Models. Perspective visualization assists in a better understanding of complex geographical areas and geological structures. For this reason, in the last few years it has been used in many applications, such as

- Urban planning: the geometry and the planning of an engineering project (a bridge or a dam) and the visual effects of planned reconstructions can be examined through visualization.
- Environmental studies: the ecological impacts of a proposed project can be thoroughly examined.
- Telecommunication applications: the morphology of the terrain has an important effect in the signal's transmission, so the 3D simulation of the anaglyph contributes in the establishment of telecommunication network stations (Graf, 1995).

6.1 Visualization of the DTM

A Digital Terrain Model can be visualized in different ways through terrain analysis, which involves the processing and graphic simulation of elevation data. In the following Figures some images are presented which are the products of the terrain analysis:

- Shaded relief image: illustrates variations in terrain by differentiating areas that would be shadowed by a light source simulating the sun.
- Slope image: illustrates changes in elevation over distance
- Aspect image: illustrates the prevailing direction that the slope faces at each pixel (Erdas, 1999).

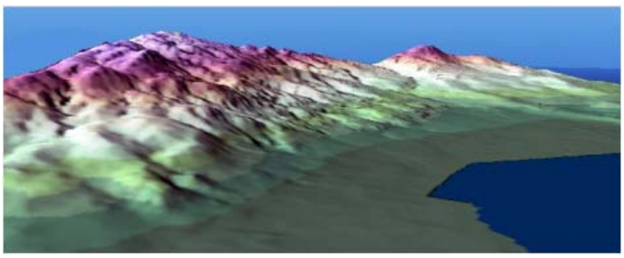


Figure 9. A painted shaded relief, which is created by splitting the elevation data into 25 equal levels and assigning a distinct colour to that level, draped over the DTM.

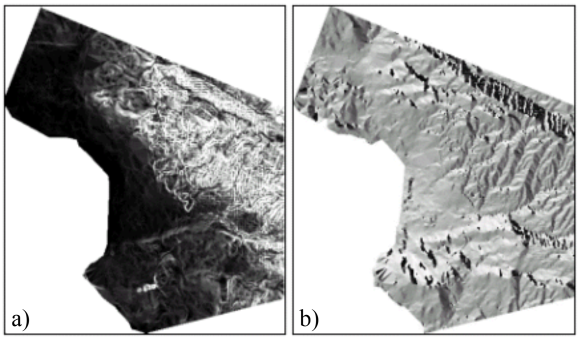


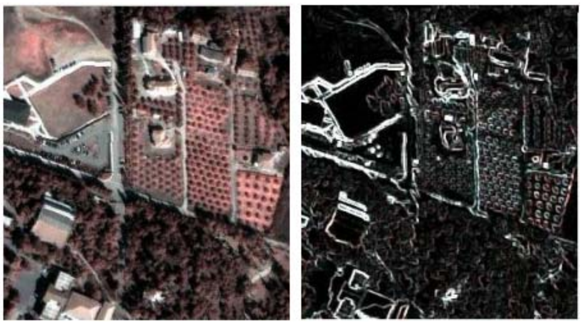
Figure 10. The slope (a) and the aspect image (b)

6.2 Visualization of the pan-sharpened image

The textural properties of an image can be useful in many applications, such as classification. Certain algorithms that detect textural features in imagery have been developed including contrast, energy, entropy, homogeneity and variance. In this study the variance operator was used, which is expressed as:

$$Variance = \frac{\sum (x_{ij} - M)^2}{n-1} \quad (1)$$

where x_{ij} = value of pixel (i, j)
n = number of pixels in a window
M = Mean of the moving window



(a) (b)

Figure 11. Textural features detected by a 3×3 window of the variance operator. a) Original and b) Texture image.

A window of 3×3 dimensions was used and the resulting image highlights the edges of the buildings, streets and vegetated areas.

7. CONCLUSIONS

This study focused on the production of accurate orthoimages as well as their further processing. During the orthorectification of the panchromatic and multispectral image a certain methodology was adopted so as to derive reliable results. It was shown that by improving the accuracy of the DTM, refining the RFCs and processing the image separately in three parts the error of the orthorectification was significantly reduced (from 35 to 3.5 m).

The fusion of the panchromatic orthoimage and the multispectral orthoimage led to a pan-sharpened orthoimage of 1-m and four bands, which preserves the spatial and spectral characteristics of both images. This conclusion is confirmed by the criteria used for the evaluation of the quality of the pan-sharpened image.

A supervised classification based on the fuzzy logic was applied initially to the whole image but did not have good results. Since the classification of urban areas is usually difficult having complex structures of various materials (asphalt, cement, glass), it was decided to classify separately the urban and the tree-covered part. This resulted in satisfactory classification for both image parts.

Finally, certain ways of visualizing the DTM and the pan-sharpened orthoimage were presented for the observation of the study area.

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