IMAGE SERVER TO DISPLAY HIGH RESOLUTION SATELLITE IMAGES FOR LOCAL PLANNING IN THE GREEK ISLAND OF NAXOS

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ABSTRACT

The processing of high resolution satellite image using open source tools in order to be usable / feasible for an open source based web application to obtain minimum storage and good quality background image is described. The use of a digital elevation model from 1:5000 scale maps with 4 meter contour interval to obtain an ortho image is also discussed and analyzed. Consequently, in order to be developed a web application using these data, the test of open source based geo-servers or map-servers which are capable to interpret the geospatial data to an acceptable web format such as WMS with reasonable speed is discussed and analyzed. A practical application of the web system which is using the high resolution ortho satellite image as a background image for local planning in the Greek island of Naxos is also presented in detail. The satellite image will be used as a background with updated local spatial information, which is necessary for the architects, to do the planning.

Keywords: web server, high resolution, ortho, open source, local planning

INTRODUCTION

This work is part of a research project operated at the Remote Sensing Laboratory (RSLUA) of the University of the Aegean: “A Prototype Land Planning of Drymalias Municipality Territory of the island of Naxos to reveal and protect its physiognomy”. The project deals with the typological consideration of the physiognomy of the Aegean islands together with the synthesis of the individual parts which is composed of. To make the results of this research project applicable, according to the existing relative legislation, there was an effort to develop the individual chapters of this research project in the form of Plans of Territorial and Ekistic Organization of Open Cities (SHOOAP) of the Municipality of Drymalias as well as in those of General Urban Planning G.U.P. which constitute the institutional frame of such type of studies.

The purpose of this work is to provide an accurate geometric framework to support the base map for the project, to provide updated background information using high resolution satellite images ortho rectified to accurately fit to the geometric structure, and, to display this information together with most planning information on an image server, thus making it available to the public. The geometric framework was based on 1:5000 scale topographic maps of 4 meter contour interval made by the Army Geographical Service of Greece (GYS) which covers the entire island. The same maps were used to digitize the 20 meter contours and create an accurate DEM for 3-D viewing of the terrain and for orthorectification purposes of the satellite images. A GeoEye-1 satellite image of 0.5 meter spatial resolution pan sharpened in four 11-bit channels, dated October 23, 2009, 09:02 GMT, was acquired and was orthorectified to be used by the architects, environmentalists and planners, providing updated background information for the planning. At this stage, the first face of the project dealing with the analysis of the existent development state of the island has been finished and the image server is under construction to carry and display all planning information. The image server is based on open source software and at the present is currying the satellite image which has been processed in such a way so that to occupy less storage space and be quite fast when displayed through the internet. The image server also is displaying some vectors such as the main and secondary road system and the effort continues to put all vector information together with capabilities of 3-D viewing of the terrain together with the satellite image and all vector features.

THE GEOMETRIC FRAMEWORK

As stated in the introduction the geometric framework is based on 1:5000 scale topographic maps of 4 meter contour interval and it is going to be discussed some detail concerning the reference system. There were used 52 such map sheets made by photogrammetric process based on aerial photographs taken in 1983 to cover the entire island; these maps are on the old reference system which is based on the Hatt projection but since 1987 a new reference system based on the Transverse Mercator projection was adopted as the official Greek system called EGSA87. The EGSA87 grid is based on a single zone for the entire country (Hatzopoulos 2008). To ensure consistency for the reference system, a 500 meter grid was first digitized on the EGSA87 system to cover the entire island so that to match the existing 500 meter Hatt grid drawn on the map sheets. This grid establishes a uniform consistent geometric framework which is used for the registration of each individual map sheet (see Figure 1).

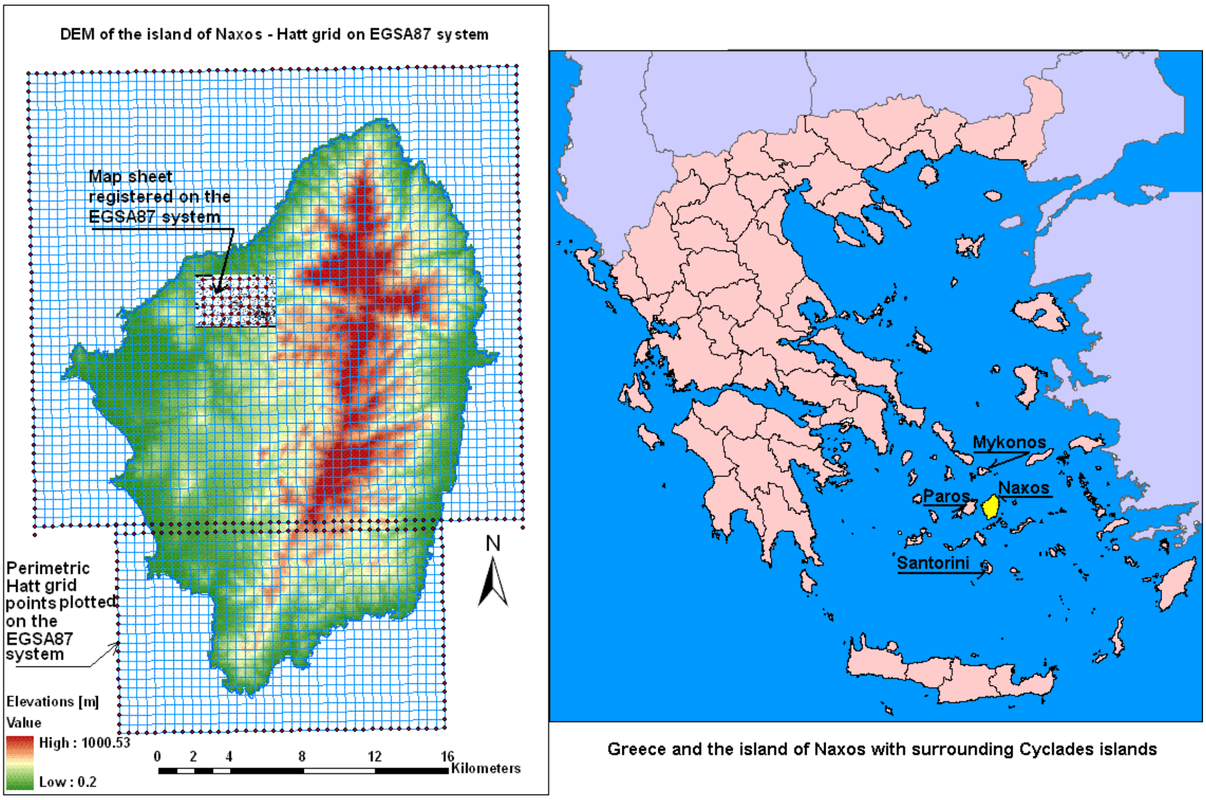

Figure 1. The Hatt grid on EGSA87 coordinate system helps to register all map sheets on this system.

As shown in Figure 1, the points on the perimeter of the grid lines were first transformed from the Hatt system to the EGSA87 system, then they were plotted using the ArcGis software and the opposite points were joined with lines horizontally and vertically to form the reference grid. Then all map sheets one at a time were registered in the correct geometric position as shown in Figure 1, by matching their grid nodes with the corresponding digitized grid ones and thus getting coordinates in the EGSA87 system.

The next step was to create a mosaic with all 52 map sheets registered in the EGSA87 system. The establishment of the grid shown in Figure 1, was of a great assistance to register precisely each individual map sheet using all legible grid nodes. The mosaic as shown in Figure 2 was created using the Erdas Imagine software and in the same Figure is also shown a detail of the matching precision of a common junction where four adjacent map sheets are merged together.

The mosaic is representing the base map for the area with all natural and human made features as they were recorded in the 1983 dated aerial photography. Many of these features are still there today such as stony walls to separate properties, terraces, hiking trails and of course most terrain relief. This mosaic is of a great importance for the municipalities representing the geometric framework with most basic features over the geographical space. Having this as a base map, then any updated information can be easily overlaid especially using high resolution satellite images.

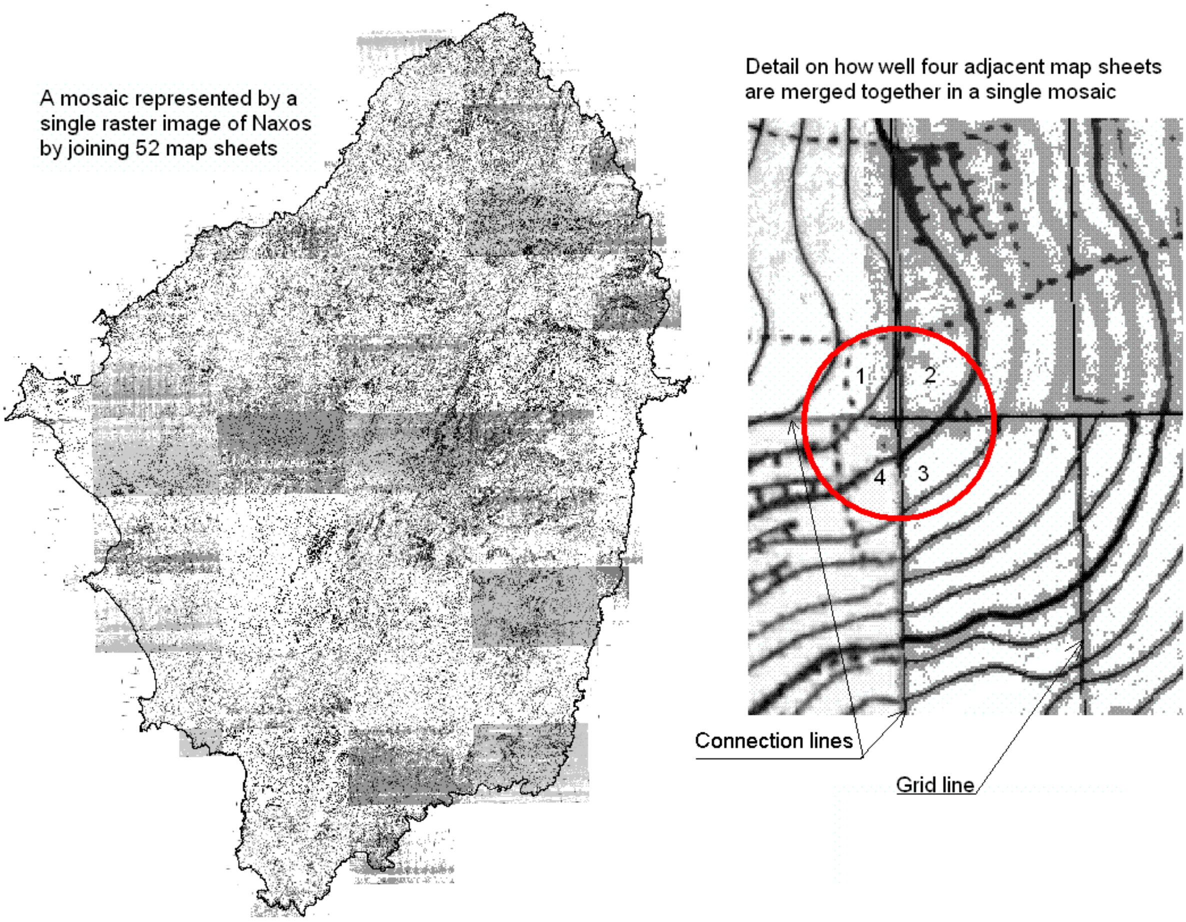

Figure 2. The mosaic of the 52 merged map sheets and a detail sowing the precision at the connections.

HIGH RESOLUTION SATELLITE IMAGES

Planning generally is based on the quality of existing information, so that any taken action to be reasonable. The high resolution satellite images provide updated information of high quality. In this project it was used a GeoEye-1 satellite image of 0.5 meter spatial resolution pan sharpened in four 11-bit channels, dated October 23, 2009, 09:02 GMT. This image was acquired and was orthorectified to cover the entire island except a very small part in the West side of the island (see Figure 3). The original image came in 8 different files acquired in two different orbits. In Figure 3 is shown the island of Naxos using the R,G,B channels for a color composite image and the IR,R,G channels for a pseudo color image. In same Figure is also shown the two different satellite orbits the East-orbit and the West-orbit. The original image had five image files on the West orbit and three image files on the East orbit, each file being less than 3 Gb of size in GeoTiff format. The original image files were orthorectified individually at the RSLUA Lab using the DEM from the digitization of the 20 meter contours from the 1:5000 scale maps using the Erdas Imagine software. The same software was used to create a mosaic of all image files in one file of .ige Erdas format of 22 Gb size. Then the .ige image was subset into seven horizontal stripes as shown in Figure 3 each file being less than 3 Gb to fit into the regular Geotiff format.

High resolution satellite images are of low costs, they provide accurate and updated information highly important for architects and planners. In Figure 4 is shown a part of the island in the region of Komiaki which is about of 650 meter in elevation and on the left is shown detail with stony walls which separate properties and terraces of cultivated fields as well as trails and settlements. On the right side of the same figure is shown how well match the vector data (asphalt road) digitized on the 1:5000 map made of 1983 aerial photographs, with the 2009 satellite image. It must be noted that this road was repaired with small changes several times since 1983.

In Figure 5 is shown a part of the satellite image from the capital of the island Chora. The entire island and also Chora have a long history of thousands of years. Some of these historical monuments ranging from the

Greek mythology to the medieval season are shown in Figure 5. In same figure is also shown how well the vector data from the 1:5000 scale maps fit with the satellite image. Regarding the coast line which is represented with yellow color, one may observe the new developments since 1983 in the construction of a new marine and the landfill of the coast to expand the commercial zone at the lower left part of the image.

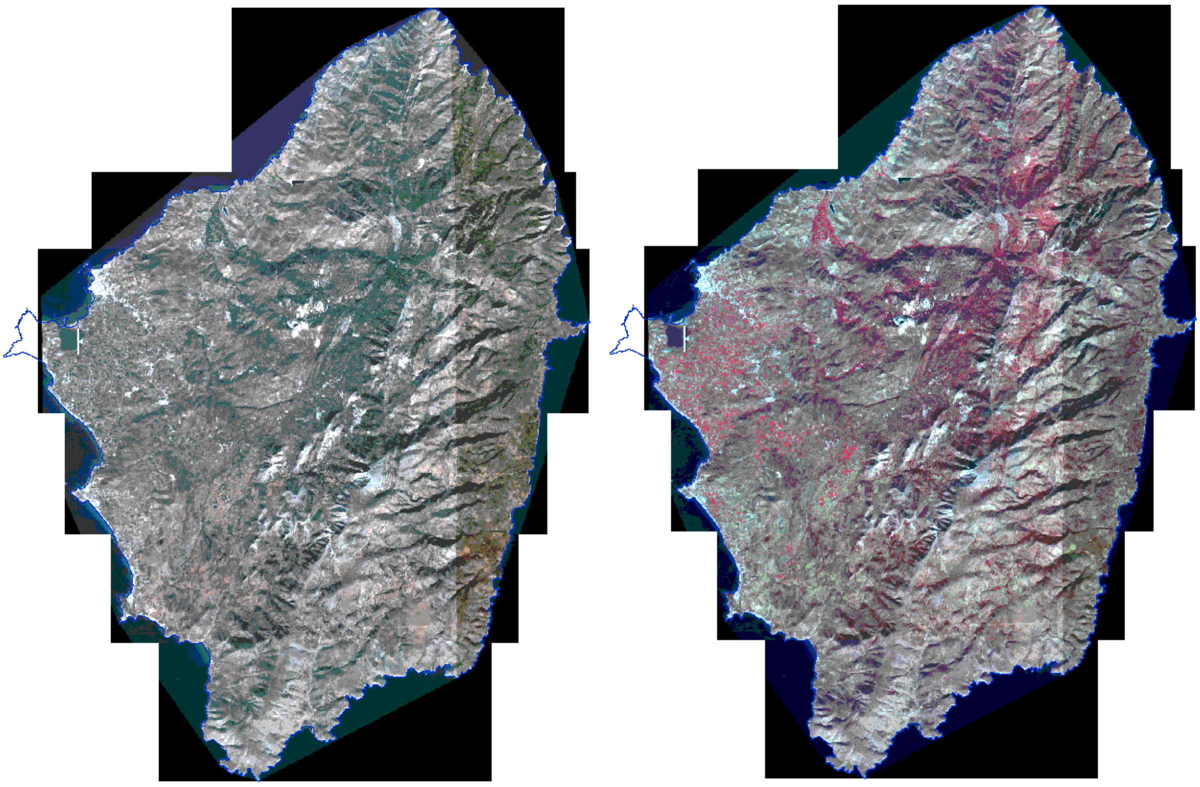

Figure 3. Left: The island of Naxos in R,G,B channels. Right: using channels IR, R, G. Satellite image of GeoEye-1 of 0.5 meter spatial resolution pan sharpened in four 11-bit channels dated October 23, 2009.

Figure 4. Komiaki region (650 m elevation) in the island of Naxos in R,G,B channels orthorectified in full spatial resolution. Left: Detail showing the stony walls and the terraces. Right: Detail showing the matching between the orthorectified image and the vectorized 1983 map road. Satellite image of GeoEye-1 of 0.5 meter spatial resolution pan sharpened in four 11-bit channels dated October 23, 2009.

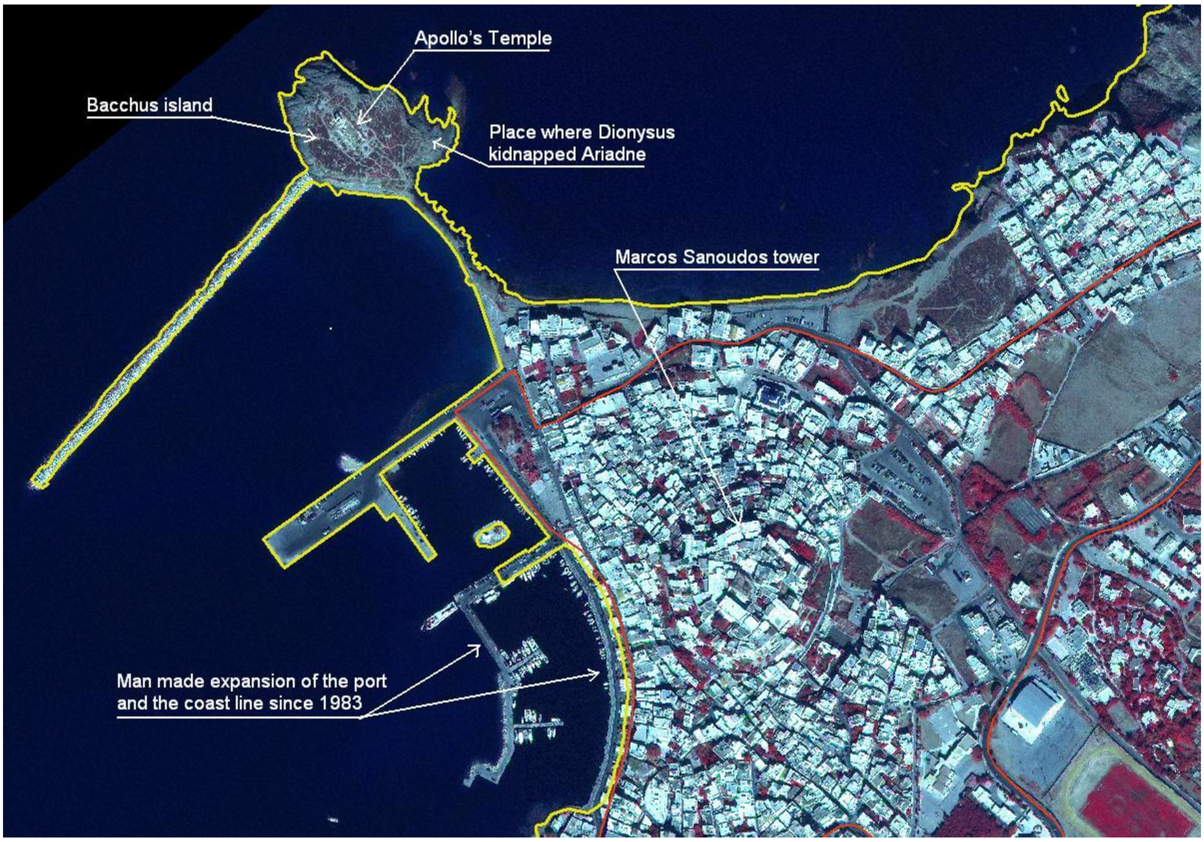

Figure 5. Chora, the capital of the island of Naxos in IR,R,G channels. Notice the lower left change in the coast line, also the matching between the orthorectified image and the vectorized 1983 map coastline (yellow) and road (red). Satellite image of GeoEye-1 of 0.5 meter spatial resolution pan sharpened in four 11-bit channels dated October 23, 2009.

ORTHORECTIFICATION PROCESS

Most high resolution satellite images use the system of push – broom to form the images. The geometry of such images is a central projection with projective center the lens as shown in Figure 6a. In Figure 6b is shown

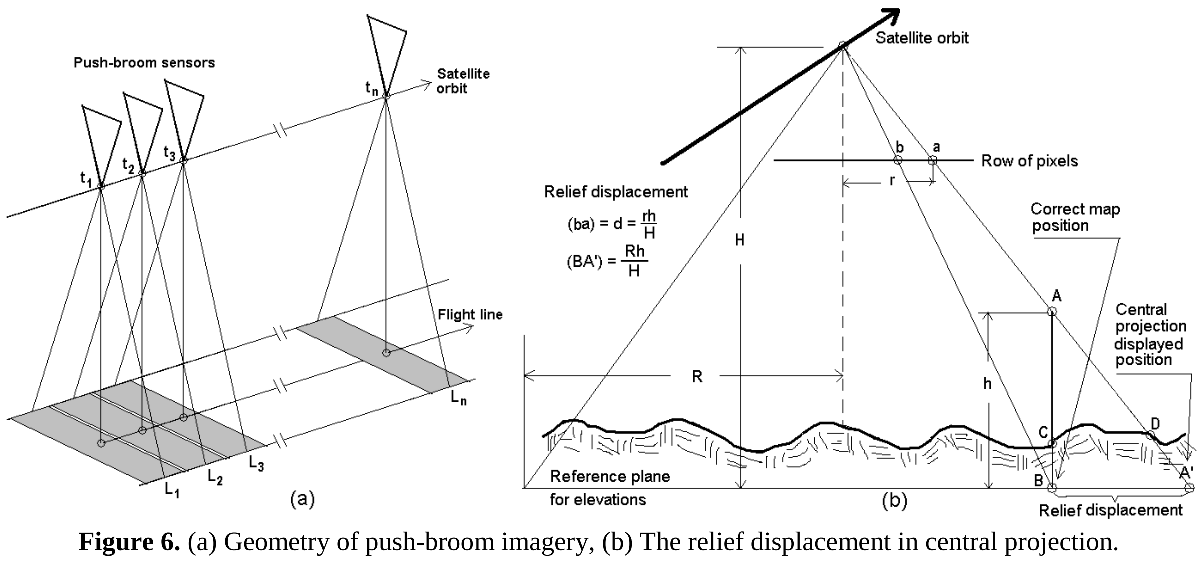

Figure 6. (a) Geometry of push-broom imagery, (b) The relief displacement in central projection.

the relief displacement effect in central projection. Central projection images are based on a projection center which usually is the lens of the camera and each object point through the lens is joined (projected) with a straight line with the corresponding image point. On the other hand maps are having an orthometric projection which is a parallel projection with projection center at infinity and direction the plumb line. In Figure 6b point A at elevation h is projected orhometrically at map point B so that A and B have the same map position, but these two points have two different images a, b, at the image plane (central projection). The image distance d = (ab) is the relief displacement and corresponding distance on the reference plane is (BA'). Assuming an elevation h = 650 m, a satellite height of 450 Km, and a scan line on the reference plane of 16 Km, then the relief displacement on this reference plane is: (BA') = Rh/H = 8x650/450 = 11.6 m. Where: R = 16/2 = 8Km. This means that the point at the reference plane, because of its elevation, could have a maximum possible displacement from its correct map position 11.6 meters. Orthorectification is the way to correct all image points from relief displacement and resample them in their correct map position. There are two ways for orthorectification, the one being by using two or more overlapping images and applying photogrammetric processes, usually two stereo images, and the second being by using one image and a Digital elevation Model (DEM) of the same area (Papapanagiotou & Hatzopoulos, 2000, Papapanagiotou et al 1997). It must be noted that most high resolution satellite systems have also the ability to take stereo images.

Most high resolution satellite images, which are geometrically corrected, are projected at a reference plane which is fixed at a certain elevation (Z = constant) usually carrying a UTM projection grid with WGS84 reference ellipsoid (Hatzopoulos 2008). All satellite image points are projected on this grid in their displaced position due to their elevation, for example, as shown in Figure 6b, ground point A, at elevation h, is centrally projected on the reference grid in location A'. The row column location of a pixel in the image file is related to the (X, Y, Z) coordinates on the reference grid by *Polynomial Rational Functions* (*PRF*) or *Polynomial Rational Coefficients* (*PRC*) which are known as the *sensor model* (see also Baltsavias E. P. & Stallmann D., 1992, Baltsavias E. P., 1996, Singh Sanjay K. et al 2008, Dial Gene et al, 2003, Dial Gene & Jacek Grodecki, 2005). A similar approach was also developed at the Remote Sensing Laboratory at the University of the Aegean between 1992 and 1998 and it was the PhD research of E. Papapanagiotou (see Papapanagiotou & Hatzopoulos, 2000). The PRF can be expressed as follows:

$$l = \frac{\text{Numerator}_L(X,Y,Z)}{\text{Denominator}_L(X,Y,Z)}, \quad c = \frac{\text{Numerator}_c(X,Y,Z)}{\text{Denominator}_c(X,Y,Z)} \tag{1}$$

Where: l, c express the location of a pixel in the image file, l, L = line, c = column,

$\text{Numerator}_L(X, Y, Z) = a_1+a_2X+a_3Y+a_4Z+a_5XY+a_6XZ+a_7YZ+a_8X^2+a_9Y^2+a_{10}Z^2+a_{11}XY^2+a_{12}XZ^2+a_{13}X^2Y+a_{14}YZ^2+a_{15}X^2Z+a_{16}Y^2Z+a_{17}XYZ+a_{18}X^3+a_{19}Y^3+a_{20}Z^3$

$\text{Denominator}_L(X, Y, Z) = b_1+b_2X+b_3Y+b_4Z+b_5XY+b_6XZ+b_7YZ+b_8X^2+b_9Y^2+b_{10}Z^2+b_{11}XY^2+b_{12}XZ^2+b_{13}X^2Y+b_{14}YZ^2+b_{15}X^2Z+b_{16}Y^2Z+b_{17}XYZ+b_{18}X^3+b_{19}Y^3+b_{20}Z^3$

$\text{Numerator}_c(X, Y, Z) = c_1+c_2X+c_3Y+c_4Z+c_5XY+c_6XZ+c_7YZ+c_8X^2+c_9Y^2+c_{10}Z^2+c_{11}XY^2+c_{12}XZ^2+c_{13}X^2Y+c_{14}YZ^2+c_{15}X^2Z+c_{16}Y^2Z+c_{17}XYZ+c_{18}X^3+c_{19}Y^3+c_{20}Z^3$

$\text{Denominator}_c(X, Y, Z) = d_1+d_2X+d_3Y+d_4Z+d_5XY+d_6XZ+d_7YZ+d_8X^2+d_9Y^2+d_{10}Z^2+d_{11}XY^2+d_{12}XZ^2+d_{13}X^2Y+d_{14}YZ^2+d_{15}X^2Z+d_{16}Y^2Z+d_{17}XYZ+d_{18}X^3+d_{19}Y^3+d_{20}Z^3$

Table 1. Part of the PRC coefficients from the GeoEye-1 image used for the island of Naxos

LINE_NUM_COEFF_1: -7.674789618318715E-04	SAMP_NUM_COEFF_1: -7.303807023545987E-03
LINE_NUM_COEFF_2: +1.202009475665107E-02	SAMP_NUM_COEFF_2: +1.021075806487744E+00
LINE_NUM_COEFF_3: -1.012292622794225E+00	SAMP_NUM_COEFF_3: +1.969464772488376E-02
…	…
LINE_NUM_COEFF_19: +4.026578327460163E-06	SAMP_NUM_COEFF_19: +1.734490106739817E-06
LINE_NUM_COEFF_20: +1.144509478938647E-08	SAMP_NUM_COEFF_20: -1.406079973929887E-08
LINE_DEN_COEFF_1: +1.000000000000000E+00	SAMP_DEN_COEFF_1: +1.000000000000000E+00
LINE_DEN_COEFF_2: -3.745393390385827E-03	SAMP_DEN_COEFF_2: -3.745393390385827E-03
LINE_DEN_COEFF_3: +6.563406402813113E-03	SAMP_DEN_COEFF_3: +6.563406402813113E-03
…	…
LINE_DEN_COEFF_19: -2.678440331331862E-08	SAMP_DEN_COEFF_19: -2.678440331331862E-08
LINE_DEN_COEFF_20: +2.142157011056287E-09	SAMP_DEN_COEFF_20: +2.142157011056287E-09

The unknown coefficients a_i, b_i, c_i, d_i, i=1,2,3, …, 20 are usually given by the Satellite system and are derived from the satellite sensor data including orbital data and ground control points. Although there are 20 coefficients four times, sometimes are used only the significant ones (see Papapanagiotou & Hatzopoulos, 2000). In Table 1 are given some of the 80 PRC coefficients from the satellite image GeoEye-1 of the island of Naxos, where: NUM = numerator and DEN = denominator, LINE = row, SAMP = column. It is important to notice that in Table 1 the denominators are the same. Equations 1 are similar with the collinearity equations in Photogrammetry (Hatzopoulos 2008) the difference being the number of unknown coefficients, which in the collinearity condition are six limited to the exterior orientation only, while in present situation are 60 and include both exterior and interior orientation (sensor model).

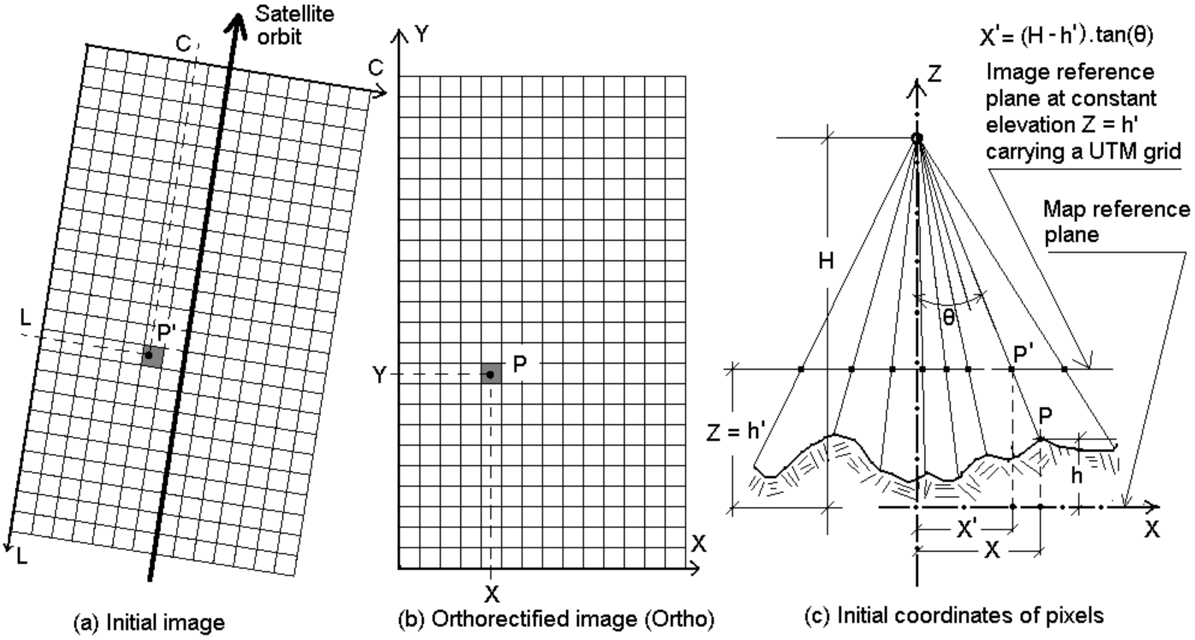

Figure 7. Original and orthorectified image with analysis of geometry for horizontal corrections when the elevation is known.

If the elevation is known, i.e. using a DEM, then the orthorectification process has to do with the correction of a point in the reference grid to a direction normal to the satellite path referred as X-direction (see Figure 7c), along the satellite path there is no relief displacement due to the push-broom geometry. Using similar triangles, the correct position X is given as follows:

$$\frac{X}{X^{'}} = \frac{H-h}{H-h^{'}} \quad \Rightarrow \quad X = X^{'}\left(\frac{H-h}{H-h^{'}}\right) = X^{'}\left(\frac{H-h}{H-Z}\right) \qquad (2)$$

Where: H is the satellite altitude, h’ = Z, is the elevation of the reference plane (carrying the UTM grid), h, is the elevation of point P, which is usually given by existing DEM.

IMAGE SERVER DESIGN AND PERFORMANCE

The most common open source tools for setting up a map server is mapserver (http://mapserver.org/) and geoserver (www.geoserver.org) for WMS (Web Map Service) standards. The original size of the image we had to deal with was of 22 Gb, which means that we had to think of separating the image into smaller pieces. GDAL (Geospatial Data Abstraction Library) is a powerful raster processing library for Gis operations and by using VRT (Virtual Raster Format) it can handle an image which is stored in pieces.

The image was not originally stretched so it was stretched properly in order to emphasize the characteristic features required by this project. It was found the min and max values of Red Blue and Green channels, the infrared channel was not involved and the information was passed into the VRT format. Using the VRT format and gdal_translate the image was converted into 8-bit tiff files, each image was about 2.6 Gb per channel. Tiff can handle up to 4Gb (we have not tested BigTiff yet). VRT image was recomposed using the three channels (see Figure 8). The most common projection for a WMS service is the EPSG:4326 or WGS84, so the tiff images were reprojected to the WGS84 system.

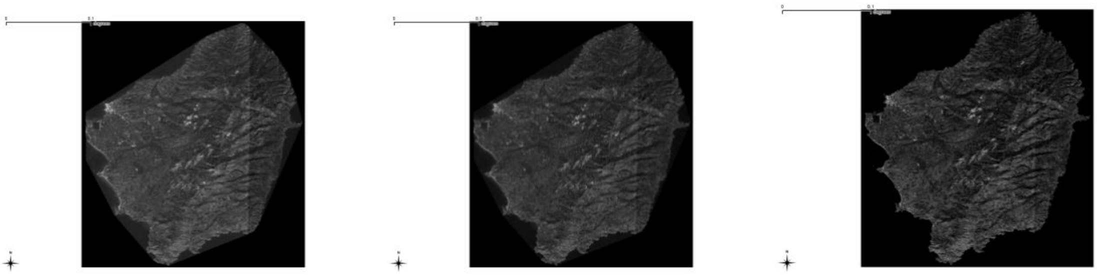

Figure 8. Gray scale of Red Blue and Green channels

Next step was to make the image tiles and pyramids and for this process the major tool is gdal_retile. It was made six pyramids and a tile size of 512x512 (see Figure 9). There was a test on tiles of size 256x256 but the size 512x512 was much more efficient. It was noticed that the zero level (high resolution) processing was becoming very heavy for the mapserver. We are using gdal_tileindex for all the zero tiles which are a total of 11960 tiles. In order to reduce the idexes we index the tiles by 500 tiles and we did the same for the level one which was 3016 tiles that had an immediate effect on the performance of the server. Tileindex is based on a DBase database and the performance of this database is slowing down when the number of records exceeds a limit.

Geoserver provides a Pyramid plugin, while in mapserver you have to define separately each pyramid level and the scale you want to see each level. We couldn’t use the same technique for geoserver as we did with mapserver. But geoserver can provide tile cache as a function of geoserver, while in mapserver you have to use some tilecache techniques from another opensource program which is a future feature for this project.

The representation of the WMS results can be developed on a webpage over the internet using a javascript application of an openlayer project. Openlayer can overlay vector data over the map or it can draw the vector data through the mapserver.

Figure 9. A tile of 512x512 pixels in map server at full resolution.

A comparison of geoserver and mapserver indicates that geoserver provides a high level GUI interface and with few option changes it can speed up the performance of the server, while in the case of mapserver it is necessary to define all the configurations in a .map files. In the long run though, geoserver hangs out due to probably DDOS attacks on the internet, while mapserver did not hang out. Mapserver provides better quality in zooming and I noticed some lines on the images were drawn in full zoom in from geoserver.

The major goal of this project was to make the terrain of Naxos with the image and the high resolution DEM in a 3D perspective. Worldwind can solve the problem, though worldwind uses its own tile system and the future work would be to adapt this system for the project.

CONCLUSIONS

There are several useful conclusions out of this experience. It was a great help for the municipality to have a single integrated map system over its territory at the scale of 1:5000, which can be used to provide reference for all individual work projects in the area. Furthermore, this map system can be used to check individual projects on how well they are prepared to fit to the national projection system EGSA87.

The high resolution satellite image as a background update information was found outstanding by the architects and planners of the project team on their effort to do the planning over the area of the municipality.

The use of high technology such as the open source map server to display through the internet the planning progress so that to be available to the public is an advanced step for active public participation in the planning process.

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