DIGITAL ORTHOPHOTOS AT A SCALE OF 1:5000 FROM HIGH RESOLUTION SATELLITE IMAGES

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ABSTRACT:

This paper describes the first results of a study, carried out within the national research program "Cofin2001", on the potential use of high resolution satellite images for making digital orthophotos at a scale of 1:5000 and 1:10,000. Particularly, images from IKONOS II and QuickBird of four different types of areas were employed: the first area is the city of Palermo, a greatly urbanized area; the second area is the extra-urban territory near the town of Contessa Entellina in south-western Sicily; the third area is the famous tourist resort of Scopello, in the western Sicily; the last area is the Caselle Airport, a flat zone near Torino. The first three images were orthorectified by using *Rational Functions Model* (RFM), varying the number of the GCP and using a DEM with 10 m grid-cell; the last image was orthorectified by using the Toutin model and a DEM with 40 m grid-cell.

1. INTRODUCTION

In recent years technological developments in Remote Sensing, and especially in spatial resolution, have opened new important perspectives regarding space cartography. As already known, the current methods of making and updating maps are based mainly on the restitution of aerial photos. Nevertheless, the production of higher geometrical resolution sensors (pixel on the ground smaller than one meter) let us suppose that in a short time satellite images will be thoroughly used even for making large scale digital maps.

Particularly, satellites equipped with sensors which permit to obtain high resolution pancromatic images (pixel from 0.61 to 2.5 m) have been sent into orbit. Such images have precision compatible with map scales of 1:25,000 and 1:10,000 as results in many tests carried on by various research groups at international level (Cheng, Toutin, 2001; Jacobsen, 2002; Vassilopoulou et al., 2002).

Therefore, by using high spatial resolution systems, today we can produce low cost medium scale maps whose accuracy is similar to the outcomes of standard aerial photogrammetry.

This described research deals only with problems concerning the use of high resolution satellite images for the production of orthophotos. Particularly, the use potentiality of the IKONOS II and QuickBird images was analysed with the aim of making orthophotos at scale of 1:10,000 and 1:5000. The orthophotos were produced for three Sicilian sites morphologically different and for the Caselle Torinese area in Piedmont.

The procedure of orthorectification was carried out for all Sicilian images by using the *Rational Function Model* (RFM); only for the image of Caselle (TO) the rigorous model of Toutin was used. The procedure of orthorectification was carried out by using *Geomatica-PCI vers.9* commercial software.

2. TEST SITES

As case study four areas were chosen, three of which are located in Sicily, respectively in the territory of Palermo, in the territory of Contessa Entellina (Palermo), and in the tourist resort of Scopello (Trapani); the last area is located in the territory of Caselle Torino Airport.

The territory of Palermo is in part built up, mainly flat and partly mountainous, with localised relieves along the margins. The altimetric variation is between 0 and 830 m.

The territory of Contessa Entellina, placed in the valley of Belice, presents a remarkable orographic variability; it varies, in fact, from a minimum quote of 131 m to a maximum quote of 561 m, with slopes which exceed 40% in some areas. Therefore, it can be considered representative of an extra urban area with a hilly character.

The territory of Scopello is largely built up with a variable morphological tendency. The altimetric range is between 0 and 700 m.

The area around the Caselle Torinese Airport is characterized by few mountainous relieves and a lot of small urban settlements.

Figure 1. The Sicilian case study in a satellite image

3. CHARACTERISTICS OF HIGH RESOLUTION DIGITAL IMAGES AND REFERENCE MAPS

The experiment was carried out on six high resolution satellite images, two of which were taken from the IKONOS II satellite on the municipal territory of Palermo and Contessa Entellina; the other five images, were acquired by the QuickBird satellite, on the territories of Palermo, Scopello, Contessa Entellina and Caselle Torinese. IKONOS images are *Geo Product* type. The IKONOS *Geo Product* is a low-accuracy georeferenced product. The features of these images are showed in the table 1. Data pre-processing consists in a geometrical correction in order to remove the distortions introduced by the acquisition geometry. The re-sampling of the image is carried out imposing a constant ground sample distance, as well as the arrangement in a specific datum and map projection. The circular error (CE90) of this IKONOS product type is about ±15 m. Table 1 describes the most important characteristics of the IKONOS *Geo* images. QuickBird images are *Standard* type for the three Sicilians areas and *Basic* type for the Caselle Torinese area.

Standard Imagery products are radiometrically corrected, sensor corrected, geometrically corrected, and mapped to a cartographic projection. Standard Imagery has a coarse DEM applied to it, which is used to normalize for topographic relief with respect to the reference ellipsoid. The degree of normalization is relatively small, so while this product has terrain corrections, it is not considered orthorectified. The Circular Error (CE90) for this product line is about ±23 m.

Basic Imagery products are the least processed of the QuickBird Imagery Products and are designed for customers having advanced image processing capabilities. *Basic Imagery*, together with the supplied attitude, ephemeris, and camera model information, is suitable for advanced photogrammetric processing (QuickBird Imagery Products – Product Guide). Table 2 shows the most important characteristics of the QuickBird images.

	Contessa Entellina (PA)	Palermo
Type	GEO Pan	GEO Pan
Acquisition Date	01/06/2000	06/04/2002
Sensor elevation	84.50231°	60.78805°
Sensor azimut	220.6225°	0.1336°
Sun elevation	66.58229°	139.1573°
Sun azimut	125.8465°	70.61002°
Radiometric resolution	11 bit	11 bit
Geometric resolution	1 m	1 m
Datum	UTM-WGS84	UTM-WGS84
Dimentions	9553 pixel x 9495 pixel	10248 pixel x 11804 pixel
	9553 m x 9495 m	10248 m x 11804 m

Table 1. Characteristics of the IKONOS *Geo* images

The following maps were used in the described experiment:
- *Palermo* - raster map at a scale of 1:2000 and raster map at scale 1:10,000 (Regional Map);
- *Contessa Entellina* - raster map at a scale of 1:5000 and vector map at scale 1:10,000 (Regional Map);
- *Scopello* - raster map at a scale of 1:25,000 and raster map at scale of 1:10,000 (Regional Map);
- *Caselle* – raster map at a scale of 1:5000 provided by the Province of Torino.

	Contessa Entellina (PA)	Scopello	Palermo	Caselle (TO)
Type	Standard	Standard	Standard	Basic
Acquisition Date	17/07/2002	11/06/2002	01/02/2002	26/09/2002
Sensor elevation	80.5597°	80.6412°	68.8072°	78.4815°
Sensor azimut	31.3294°	105.7075°	87.0227°	249.016°
Sun elevation	66.6436°	68.6976°	62.0918°	32.5551°
Sun azimut	129.076°	128.8707°	139.947°	159.251°
Radiometric resolution	16 bit	16 bit	16 bit	16 bit
Geometric resolution	0.70 m	0.70 m	0.70 m	0.62 m
Datum	UTM-WGS84	UTM-WGS84	UTM-WGS84	UTM-WGS84
Dimentions	7260 pixel x 7176 pixel	7148 pixel x 7546 pixel	7240 pixel x 7260 pixel	28684 pixel x 27552 pixel
	5082 m x 5023 m	5003 m x 5284 m	5068 m x 5082 m	17784 m x 17082 m

Table 2. Characteristics of the QuickBird images

4. GROUND CONTROL POINTS AND CHECK POINTS

Ground Control Points (GCPs) and Check Points (CPs) necessary to orthorectify the satellite images and to control the orthophotos accuracy, were collected both by using GPS method (Smith D. P., Atkinson S. F., 2001) and by extracting point coordinates from high scale maps.

The points surveyed with GPS were previously identified on the images then, verified the possibility of standing on the ground, a static-rapid method was employed with acquisition time of about 20' and rate of 5'', by using three double-frequency Topcon Legacy-H GPS receivers.

A well-distributed pattern of points was selected spaced uniformly throughout the study area. Where possible, the points were located on the country plain close to artificial elements (corner of pavements and flowerbeds, crossroads, outcrop of rocks). The accuracy of their coordinates was in order of few centimetres. Extracted data were processed in WGS84 reference system, by using *Pinnacle 1.0* software. Subsequently all the coordinates were transformed in the National Map System (Gauss-Boaga), using a seven parameters transformation available from the points of the IGM95 National GPS network closer to test sites.

A part of the control points and check points was extracted by the official maps which had a larger representation scale than the one of the digital ortophotos.

On the whole, 70 points were considered both on the territory of Palermo and Contessa Entellina, and 60 points on the territory of Scopello. For the Caselle image a set of 18 points, equally divided in GCPs and CPs, was used.

5. ALTIMETRIC DATA

The DEMs used to ortorectify images were extracted from the reference maps.

Particularly, for the territory of Palermo and Contessa Entellina two DEMs were produced by digitalization of the contour lines of the Regional Map and interpolation with a grid-cell of 10 meters.

For the Scopello area, a DEM was produced by digitalization of the contour lines of a maps at scale 1:25,000 with grid-cell of 50 meters.

Finally a DEM with a grid-cell of 40 meters was used to orthoproject the QuickBird *Basic* image of Caselle Torinese (TO).

6. ORTHORECTIFICATION

In order to make the orthorectification it is necessary to use a mathematical model which allows to put in relationship pixel-coordinates into the image space with coordinates of the corresponding points into the object space.

In the described experiment, orthoprojection were executed by using *PCI Geomatica 9.0 Orthoengine* module. This software allows to use the following four different models:

- ➢ *Satellite Orbital Modeling (this class include the Toutin model)*
- ➢ *Polynomial Model*
- ➢ *Thin Plate Spline Model*
- ➢ *Rational Functions Model (RFM)*

All these, except for the *Toutin model*, are non-parametric models. In the non-parametric models the transformation between image space and object space is performed through mathematical functional relations that don't need an aprioristic knowledge of the parameters describing the platform, the sensor and the projection system.

To choose the proper model, it was necessary to consider that:

- ➢ in the case of IKONOS image, there was a lack of information (satellite and sensor data), which didn't permitt to work with a rigorous model;
- ➢ images were provided geometrically pre-processed;
- ➢ in the three examined cases, investigated territory showed significant altimetric variations.

This combination suggested the opportunity to apply the *Rational Function Model* (RFM) (Dial G., Grodecki J., 2003). This is a non parametric model, constituted by four polynomial functions: the ratio of two polynomial functions is used to calculate row pixel (i) positions and the ratio of the other two functions is used to calculate column pixel (j) positions. Polynomial are shaped as follows:

$$i = \frac{P_1(X,Y,Z)}{P_2(X,Y,Z)}$$

$$j = \frac{P_3(X,Y,Z)}{P_4(X,Y,Z)}$$

$$P = \sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m3} a_{ijk} X^i, Y^j, Z^k$$

Coefficients (a_{ijk}) in the functions, named *Rational Polynomial Coefficients* (RPC), can be different in number, depending on the grade of the polynomial. They can be known, since they are given by the image agency which distributes image, or they can be calculated indirectly, through a number of GCPs equal to: 2n-1, where "n" is the number of RPC coefficients.

In order to orthorectify the IKONOS *Geo* and QuickBird *Standard* images, the RFM model was used. Particularly the model was used with two configurations of 10 and 20 coefficients. The coefficients was calculated starting from a set of 19, 25, 30, 39, 45 and 55 GCPs. Another set of 15 points (CPs) was considered to check the geometric accuracy of the ortorectified product. The *Basic* QuickBird image of Caselle Torinese was orthorectified by using the parametric model of Toutin, which requires a low number of GCP: in this case, a set of 9 GCPs and 9 CPs was used.

Figures 2 and 3 show the location of GCPs and CPs on the IKONOS images; figures 4, 5. 6 and 7 on the QuickBird images.
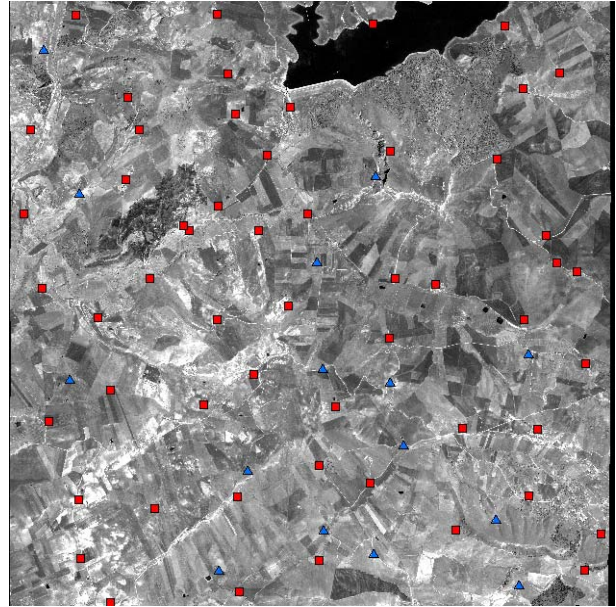

Figure 2. GCPs (red color squares) and CPs (blue color triangles) on the IKONOS image of Contessa
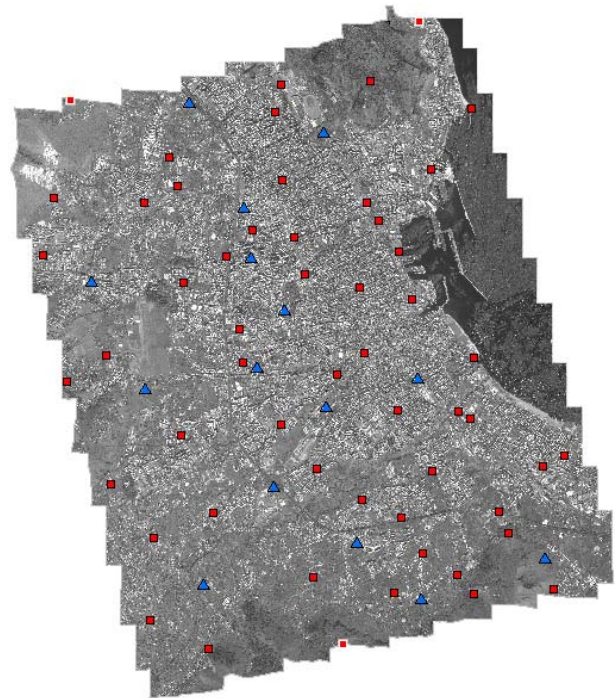

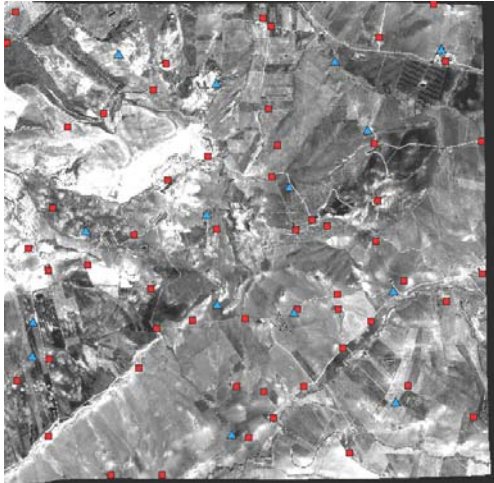Figure 3. GCPs (red color squares) and CPs (blue color triangles) on the IKONOS image of Palermo

Figure 4. GCPs (red color squares) and CPs (blue color triangles) on the QuickBird image of Contessa
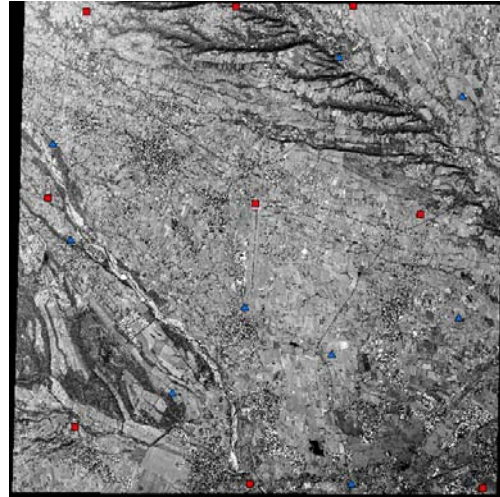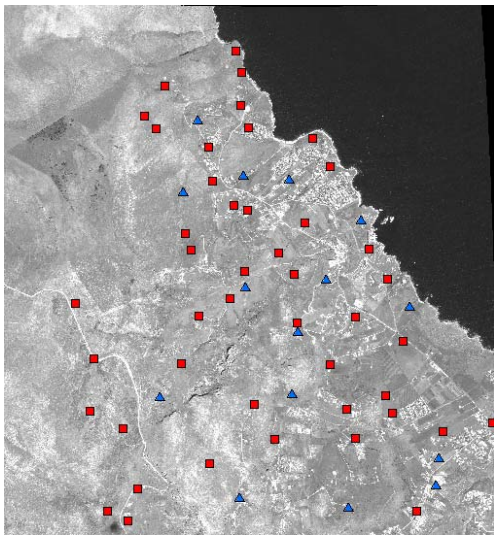

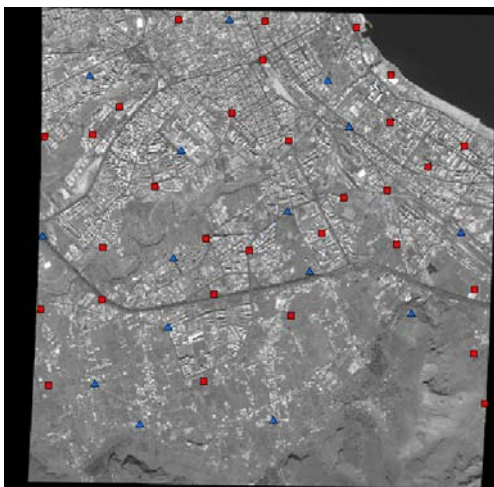Figure 5. GCPs (red color squares) and CPs (blue color triangles) on the QuickBird image of Scopello

Figure 6. GCPs (red color squares) and CPs (blue color triangles) on the QuickBird image of Palermo

Figure 7. GCPs (red color squares) and CPs (blue color triangles) on the QuickBird *Basic* image of Torino Caselle

The statistical parameters which were calculated are: RMS values in X and Y, relative to GCPs and CPs (RMS X, RMS Y) and the total RMS values. These results are briefly shown in 3, 4, 5 and 6 tables.

Contessa Entellina - IKONOS II							
10 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
19	0.63	0.70	1.04	15	2.16	2.36	3.28
25	0.96	1.45	1.50	15	2.62	3.01	3.41
30	1.07	1.63	1.69	15	2.10	2.40	3.33
45	1.14	1.77	1.79	15	1.87	2.36	3.04
55	1.16	1.81	1.77	15	2.11	2.32	3.38
20 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
39	0.59	0.58	0.85	15	1.42	1.80	2.29
45	0.69	0.84	0.86	15	1.20	1.66	1.73
55	0.63	1.02	0.88	15	1.07	1.60	2.25

Table 3. GCPs and CPs RMS relative to the IKONOS image of Contessa Entellina

Palermo - IKONOS II							
RFM 10 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
19	0.22	0.21	0.35	15	1.40	1.46	1.71
25	0.54	0.42	0.73	15	1.25	1.37	1.50
30	0.50	0.54	0.81	15	1.30	1.23	1.62
39	0.81	0.58	1.12	15	1.21	1.14	1.64
45	0.86	0.91	1.12	15	1.19	1.06	1.60
55	0.86	0.90	1.14	15	1.23	1.05	1.64
20 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
39	0.48	0.21	0.60	15	0.59	0.58	0.85
45	0.67	0.61	0.77	15	0.69	0.84	0.86
55	0.76	0.67	0.92	15	0.63	1.02	0.88

Table 4. GCPs and CPs RMS relative to the IKONOS image of Palermo

Contessa Entellina - QuickBird							
10 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
19	1.90	0.98	2.65	15	2.88	3.44	5.69
25	1.93	1.08	3.41	15	3.08	3.43	5.55
30	1.90	1.40	3.20	15	3.12	3.97	5.34
45	2.28	2.08	3.14	15	2.01	2.26	4.31
55	2.36	2.17	3.45	15	1.96	2.25	4.14
20 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
39	1.06	0.85	1.76	15	2.17	3.17	8.40
45	1.03	0.93	1.74	15	2.02	3.18	7.80
55	1.88	1.52	2.75	15	2.67	4.81	10.91

Table 5. GCPs and CPs RMS relative to the QuickBird image of Contessa Entellina

Scopello - QuickBird							
10 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
19	1.84	2.45	0.55	15	3.80	5.81	1.07
25	1.82	2.55	0.86	15	3.59	5.71	1.10
30	1.65	2.47	0.91	15	4.26	6.14	1.34
39	1.75	2.82	0.90	15	5.07	7.12	0.90
45	2.09	3.40	0.93	15	4.63	6.89	0.82
20 coeff.							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
39	0.48	0.78	0.50	15	2.28	3.79	1.22
45	0.56	0.93	0.54	15	2.08	3.49	1.22

Table 6. GCPs and CPs RMS relative to the QuickBird image of Scopello

Caselle Torinese - QuickBird							
Toutin Model							
RMS GCPs				**RMS CPs**			
N. GCP	XY RMS	X RMS	Y RMS	N. CP	XY RMS	X RMS	Y RMS
9	1.00	1.60	1.85	9	1.06	3.22	3.30

Table 7. GCPs and CPs RMS relative to the QuickBird *Basic* image of Caselle Torinese

All these tables show that in all the examined cases acceptable results were achieved, and the geometric accuracy of orthorettified images is quite similar to map tolerance of a traditional map scale of 1:5000.

Regarding the QuickBird image of Palermo, comparable results were not obtained: this behavior is probably due to distortions affecting image and to a pre-processing phase in which the product was irreparably damaged. In this case, a geometrical accuracy higher than the circular error of the image, was not obtained.

The possibility to obtain a product compatible with the above-mentioned scale was tested on a QuickBird Basic image centred on Torino "Caselle" Airport. This image was submitted only to the radiometric corrections, so that it was possible to use the Toutin model. By using Toutin model an orthorectification with support of 9 GCPs was carried out; this orthorectification has led to excellent results, totally consistent with a map scale of 1: 5000 (Tab. 7).

7. ANALYSIS OF RESULTS

A first order of control was carried out by the visual overlap between the ortophotos and the Official Maps.

The figure 8, regarding a subset of Palermo IKONOS image, shows an example of this control.

Figure 8. Overlay between the Municipal Map of Palermo and the orthophoto obtained by the IKONOS Palermo image

The last control regards the comparison between the coordinates of some points extracted by the orthophoto and the coordinates of the same points extracted by a reference map. In this regards 30 couples of points for the IKONOS *Geo* images and 20 couples of points for the QuickBird *Standard* images were considered.

The figures 9, 10, 11 and 12 show some examples with charts describing the frequency histogram of the couples of points observed.
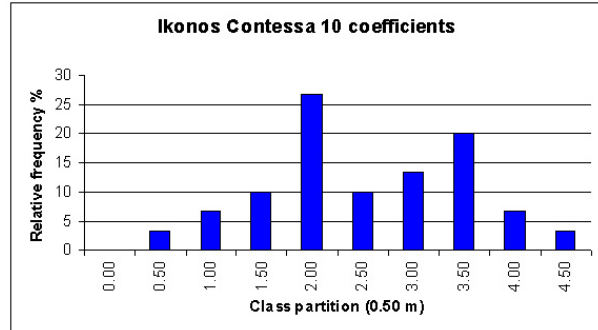

Figure 9. Frequency histogram relative to IKONOS image of Contessa Entellina
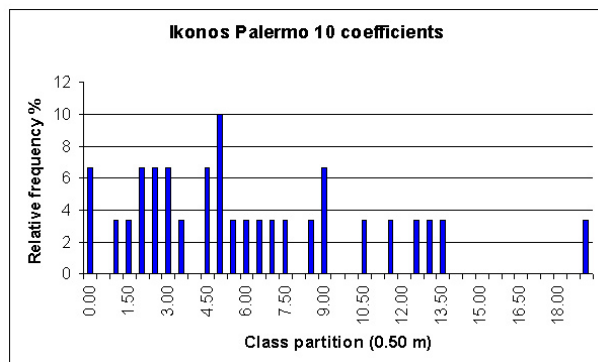

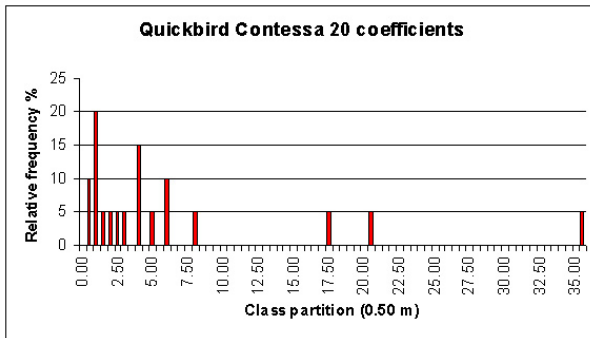Figure 10. Frequency histogram relative to IKONOS image of Palermo

Figure 11. Frequency histogram relative to QuickBird
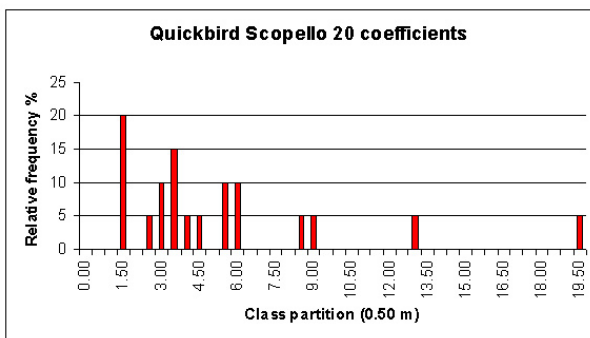image of Contessa

Figure 12. Frequency histogram relative to QuickBird
image of Scopello

Regional Maps at a scale of 1:10,000 were used as reference maps; these maps are available in vector format for the territory of Contessa Entellina and in raster format for the territories of Palermo and Scopello.

Test operations were carried out through an application, written in *Avenue* language in ArcView environment.

8. CONCLUSIONS

The current availability of high resolution satellite images permits to develop a methodology alternative to the photogrammetric one for the production of medium scale orthophotos through the association of a single image to a suitable DEM. In this regard the described work research demonstrated that the geometrical accuracy obtained by using IKONOS *Geo* and QuickBird *Standard* images is compatible with map scales of 1:10,000 and, sometimes, of 1:5000, despite limits of such kind of data. For this reason it looks right to investigate deeper the use of satellite images for making maps. In this specific test pre-processed images and non-parametric models were used. Nowadays, more interesting possibilities are open to researchers, for example the analysis of not pre-processed images, or, when possible, the use of right math correction models, or, finally, the availability of stereo images. Moreover, it is important to emphasize the advantage in simplifying the image orientation procedures compared with traditional photogrammetric ones. That is because a single satellite scene covers a larger area than a single aerial photograph at the same scale.

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