High resolution satellite images orthoprojection using dense DEM

Article *in* Proceedings of SPIE - The International Society for Optical Engineering · March 2003

DOI: 10.1117/12.463153

2 authors:

Andrea LINGUA
Politecnico di Torino

Enrico Borgogno Mondino
Università degli Studi di Torino

High resolution satellite images orthoprojection using dense DEM

Andrea Lingua[*a], Enrico Borgogno Mondino[a]
[a]Dipartimento di Georisorse e Territorio, Politecnico di Torino

ABSTRACT

According to the recent incoming of high resolution images acquired by the new earth observation satellites (IKONOS, EROS, QUICKBIRD) we are suggested to considered their possible photogrammetric exploitation. The high geometric resolution of such images (up to 0.6 m GSD) and their high radiometric resolution drive us to consider them as possible substitutes of the classic aerial images used for cartographic purposes at the 1:5000/1:2000 scale. In such context we can't omit the heavy incidence of terrain altimetry onto the images georeferencing operations; orthocorrection is necessary to be carried out. This paper, far away from solving the real orthoprojection instances related to the definition of the camera position and attitude, demonstrates as well complex urban DDEM (Dense Digital Elevation Model) completed with volume information of buildings, can improve the planimetric accuracies of the orthocorrected images. A proprietary software, developed by the authors, can automatically extract buildings DEM from a 3D cartography and integrate it with a simple terrain DEM. Results are referred to an orthocorrection carried out by a commercial software. They are certainly conditioned by the out-of-our-control geometric model used by the software itself. The purpose is simply to demonstrate the real improvement of the planimetric positioning obtained using DDEM.

Keywords: DEM, high resolution images, urban areas, digital cartography, digital orthophoto, planimetric accuracy.

1. INTRODUCTION

GIS techniques are useful to solve many different problems in the field of engineering, environmental and geology applications. Cartographic vectorial data (digital cartography) represent the geometric base of GIS; satellite and aerial digital images are nowadays commonly used to easily update and integrate the existent cartography. An effective use of such approach, expecially in the case of high resolution images, can't be carried out without taking into consideration a rigorous geometric correction of this type of data; otherwise the geometric overlapping of digital vectorial cartography onto the images could not be guaranteed. Dealing with high resolution images simple georeferencing techniques must be abandoned and the approach to the problem has to be a photogrammetric one and the goal is the production of a digital ortophoto.

The digital orthophoto is an efficient and economic product that correctly represent, in a photographic form, the plane projection of any three-dimensional object. The geometry of this particular photograph is obtained through the orthogonal projection of the object on a plane in such a way that the result is metrically correct: it is possible to easily measure the represented object on the orthophoto in a known scale and read the bi-dimensional co-ordinates of significant points, exactly as on a map.

If the surface of the object is continuous (smooth), it can be described in an efficient way using a regular grid (DEM=Digital Elevation Model) whose mesh dimensions depends on the representation scale (usually greater than 10-50 m). The orthoprojection of a continuous surface is quite simple and it can be obtained using any of the numerous commercial software packages that are available on the market; it guarantees an accuracy that is acceptable for the most application fields. Unfortunately, in many cases this condition does not occur. Scene including buildings, roads, bridges and other human structures can not be correctly described with a simple DEM. The orthoprojection of these types of objects requires more refined procedures. The solutions that are presently most widely used take advantage of a regular grid with breaklines or of digital surface models (DSM) that supply a complete mathematical description of the form of the object through a set of geometric primitives (plane and quadratic). In both cases, the production of orthophotos requires very complex algorithms and long processing times.

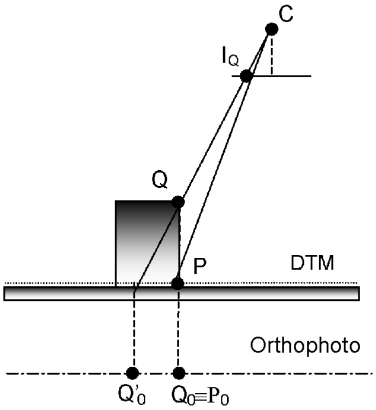
[*] email: lingua@polito.it, borgogno@polito.it; phone +39-11-5467700; fax +39-11-5647699; Politecnico di Torino, Dipartimento di Georisorse e Territorio, Corso Duca degli Abruzzi n. 24, 10129, Torino (TO), ITALY

In this article, the authors describe and test a solution that is based on the use of a dense digital elevation model (DDEM), whose mesh size is of few meters (1-5 m) and which offers the full advantages of a true digital orthophoto: a metrical high accuracy and a complete automation of the production procedure. The generation of the DDEM has been performed through complex interpolation techniques using 3D digital cartography.

This proposed procedure is directly derived from digital aerial photogrammetry: it has been applied to high resolution images acquired by satellite platform that are able to perform some application of medium and large scale cartography.

2. RIGOROUS ORTHOPROJECTION OF DISCONTINOUS SURFACE

Let us consider a building as shown in figure 1. If the DEM only describes the smooth surface of the terrain, the projection of point Q generates the wrong position Q'_0 instead of the correct position Q_0 that converges with the orthoprojection P_0 of the point P (effect 1). Figure 2 shows this practical effect: the building base is represented in a correct position, but the building roof is moved in a wrong position.



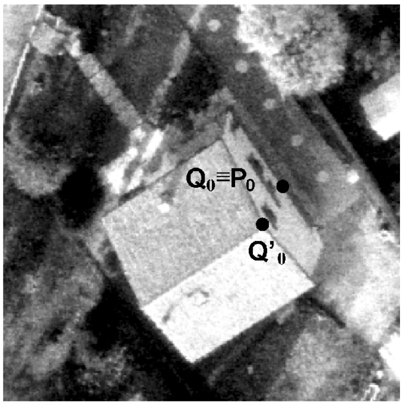
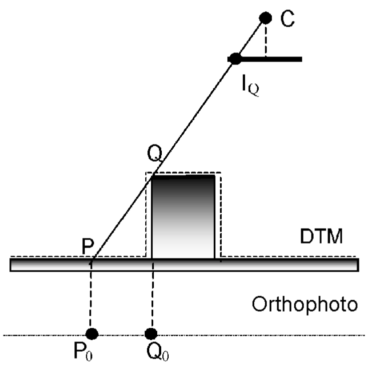


Figure 1: Orthoprojection with wrong shape description

Figure 2: A practical example

Now, let us consider a buiding described by means of a correct DEM (see figure 3). If one uses the traditional approach to digital orthophoto generation, all the points hidden by the perspective effects are not represented and the visible points are duplicated on the resulting orthophoto (effect 2). For example, the radiometry of point Q is recorded twice: the first time in Q_0, when point Q is orthoprojected, and the second time in P_0 when one tries to orthoproject the hidden point P. Figure 4 shows a realistic demonstration of this systematic error which originates from the uncompleted radiometry description of the object using a single perspective image.



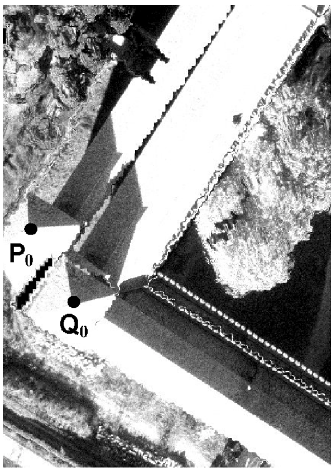


Figure 3: Orthoprojection with hidden zones

Figure 4: A practical example

Now, let us consider a bridge (see fig. 5) described by means of a correct DEM with a mesh size too large (generally 10-50 m) for large scale cartographic application in urbane zone (accuracy 0.5-2 m). The orthoprojection procedure requires the DEM interpolation to determine the height for each pixel of the orthophoto (size 0.2-2 m): if the object surface is discontinuos, this elaboration returns wrong results (effect 3). For example, the DEM interpolation moves the point P on the bridge base in the wrong point P'. The projection of P' on the image returns the image point $I_{P'}$ that don't coincide with the correct image point I_P. The final effect is shown in fig. 6: the bridge shape in the orthophoto image is irregular.

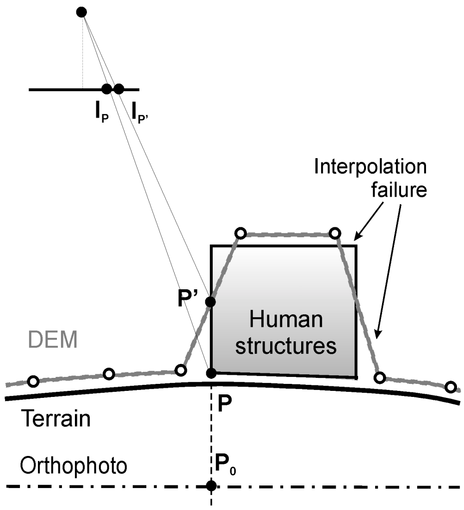


Figure 5: Orthoprojection of human structures using large mesh DEM

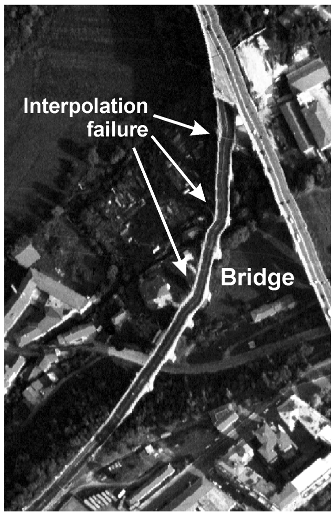


Figure 6: A practical example

Considering the previously mentioned effects, it can be stated that, in order to generate a true orthophoto of an unsmoothed object, a correct shape description and a complete image recording of all points of the object must be used. This last requirement can be accomplished only by using different images of the object itself and by avoiding the possibility of using the grey (or colour) value of a point Q for the orthoprojection of a point P lying on the same perspective ray.

3. 3D MODEL GENERATION

The build up of a correct 3D-shape description of an unsmooth object can be obtained using different approaches.

The first class of solutions tries to minimize the number of points and geometric information required to give a complete 3D description. A first approach is based on the use of a regular grid integrated by means of all the breaklines needed to describe the height discontinuities [5]. Simply considering the urban zone, it is clear that the survey of all the breaklines would mean plotting almost the entire object: the survey of the break-lines is not automatic and therefore not economic for an orthophoto generation (see fig. 7a).

The second solution is the definition of a DSM using geometric primitives to describe the boundaries of the object [4] (see fig. 7b). This last approach has been studied in detail and set up to model buildings in urban areas: plane triangles and quadrangles are defined as geometric primitives and a relational database is used to manage this sophisticated instrument. The generation of a DSM cannot be automated; the setting up and the management of such an instrument require complicated software and a large amount of computation time.

Dense irregular grids (see fig. 7c) represent the second class of tools that are useful to describe the shape of an object, where the distance between two points ranges from 2 m to a few centimeters. In these models, the density of the points replaces the intelligence of the previous solutions. It is possible to conceive four different ways of generating a DDEM.

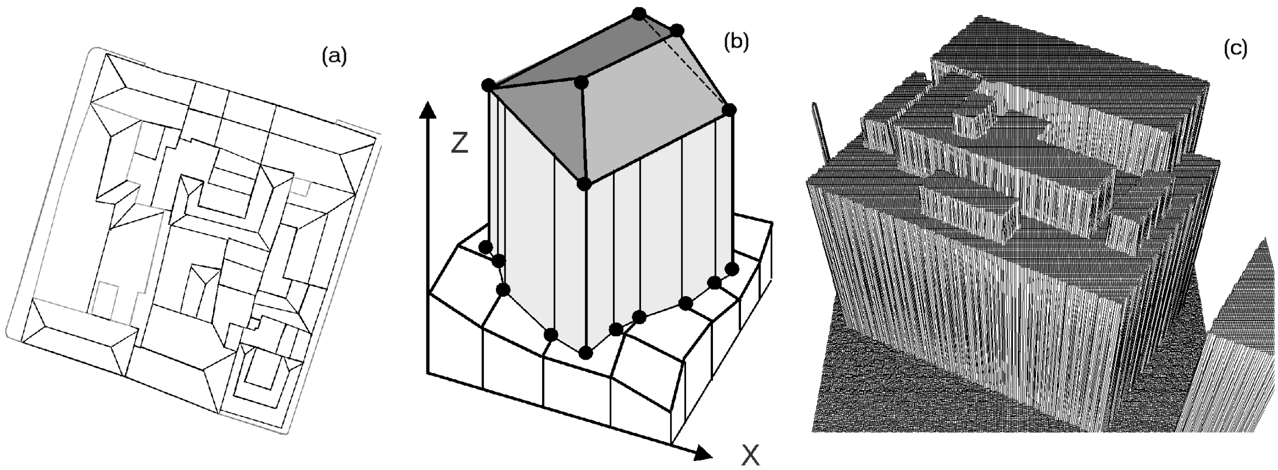


Figure 7: 3D model solution: DEM+breaklines (a), Digital Surface Model (b), dense DEM (c)

The first is the manual survey of the points. Let us consider a single map (about 60 cm x 50 cm at 1:5000 scale), an acquisition of one point each 2 m in the X and Y directions and a speed of acquisition of 0.5 s per point: an experienced operator, working 6 hours a day, could record this dense grid in 36 days!

The second possibility is the use of matching algorithms for automatic DEM generation. It is well known that this solution gives almost 70% of the required points, or much less in case of critical situations: the remaining points must be corrected or integrated manually by an operator. It is obvious that these two possibilities are not able to construct a DDEM in an economic way.

The third way of generating a dense grid is the use of modern aerial laser scanners. These surveying devices are able to acquire thousands of points with high accuracy. The laser scanner technology, based on optical-electronic devices, uses a high intensity pulse directed towards the zone to survey, in order to have a distance from the device itself. A digital image is derived from thousands of different pulses where all the measurements on single points are pure 3D locations. Over recent years a great deal of tests have been carried out on the use of airborne laser scanners for deriving high precision DEM, with the precision being independent of the distance between sensor and target. The grids generated by aerial laser scanners are irregular; X and Y spacing depends on the instantaneous range and direction of the ray between the instruments and the measured point: this means that it is possible to manage the density of the points by simply changing the acquisition distance (relative height of aeroplanes). The acquisition process is completely automatic and the DEM generation of any object (acquisition and processing of the data) is an easy and quick procedure. For these reasons the DEM generated by a laser scanner device can be considered the optimal solution for a correct and complete 3D description of the shape of a complex object, both from the technical and economic points of view.

3.1 DDEM generation using 3D digital cartography

The fourth possibility for the generation of a DDEM is based on the use of refined interpolation techniques applied to a three-dimensional digital map of the object. A digital map derived from photogrammetric techniques constitutes a three-dimensional description of simple geometric elements (points, open lines and closed lines). These elements, though simplified, permit to reconstruct a DDEM that correctly describes the existent discontinuities related to human structures:

- the terrain surface is described using isolate points or contour lines;
- each entity is coded and represented by means of 3D point; road, bridge, railway are described using polygon entities with 3D vertexes;

- buildings are described as volume entities with uniform roof height whose value is recorded inside each entity by means of a centroid. In this way, buildings can be approximated using a vertical extrusion from the terrain to roof height.

This set of information permits a correct 3D interpretation of terrain and human structures. In fig. 8, an example of 3D view of a digital cartography of the City of Perugia (Italy) is shown.

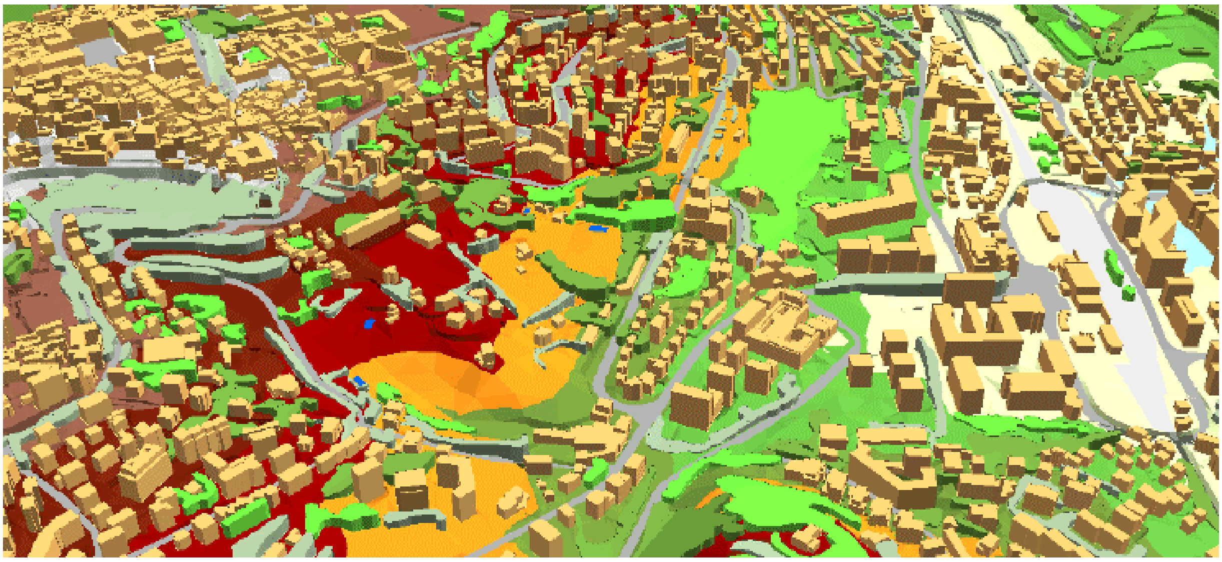


Figure 8 –3D digital cartography of the city of Perugia (Italy)

3.2 The software GeneDDEM

An original software (in Visual Fortran language) has been developed for this purpose; it automatically generates a DDTM with a redefined grid dimension, starting from a photogrammetric restitution. This software recognises the surface entity on the basis of the code and uses it in the correct way for interpolation.

The input data is a 3D digital cartography in DXF format, a set of interesting codes (points, contour lines, buildings, centroid, road, railways, rivers and others) and a set of parameters for DDEM generation (file name, mesh size, interpolation algorithm). In fig. 9, some windows of this software are shown (principal, data introduction, elaboration).

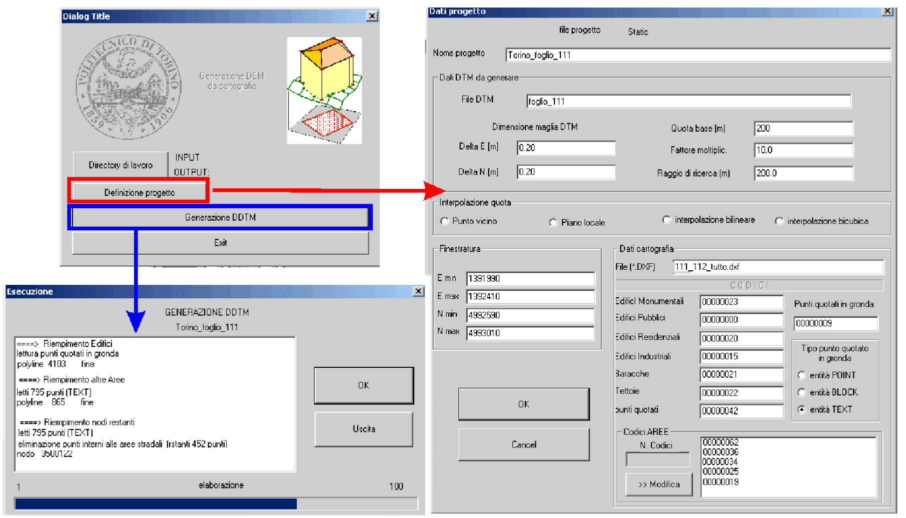


Figure 9: Some user interface windows of GeneDDEM

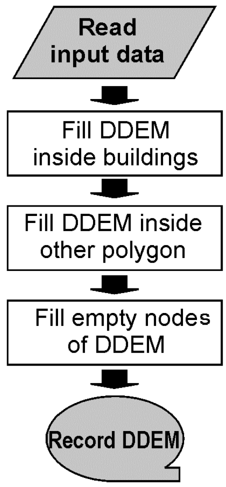


Figure 10: GeneDDEM steps

GeneDDTM operates in 4 steps (see fig. 10) that are shown inside elaboration window with a progress bar (see fig. 9):

1. filling building polygons with centroid height: extraction of centroid from DXF file (point set 1), sequential reading of polylines with correspondent code (buildings), search of centroid inside the current building polygon, filling of the DDEM nodes inside building polygon with this centroid height;

2. filling other polygon: extraction of height points and contour line vertexes from DXF file (point set 2), sequential reading of polylines with correspondent code (road, bridge, etc.), extraction of the points inside current polygon from point set 2 (point set 3), interpolation of DDEM nodes inside current polygon using point set 3 and boundary vertexes, elimination of points inside current polygon from point set 2;

3. filling empty nodes of DDEM (terrain) by means of interpolation applied to point set 2.

4. recording DDEM file in binary format (each height is an integer number) and compiling a description file (sample and line number, mesh size, georeferencing parameters) that is necessary for a direct importation in a commercial software for image elaboration (ENVI by Research System).

The interpolation algorithms, that are implemented in this software, is nearest neighbour, least squares local plane, bilinear splines, bicubic convolution [1,2,3].

Fig. 11 shows an example of GeneDDEM results: a part of 3D digital cartography (scale 1:2000) of the City of Torino (ITALY) is shown in (a), the relative DDEM (mesh size 0.2 m) generateted with GeneDDEM is shown in (b). The computation time, that has been required for this example, is about 2 hours (2300x3400 nodes, bilinear convolution) using PC standard (Pentium 4, 1500 Mhz, 512 Mb RAM).

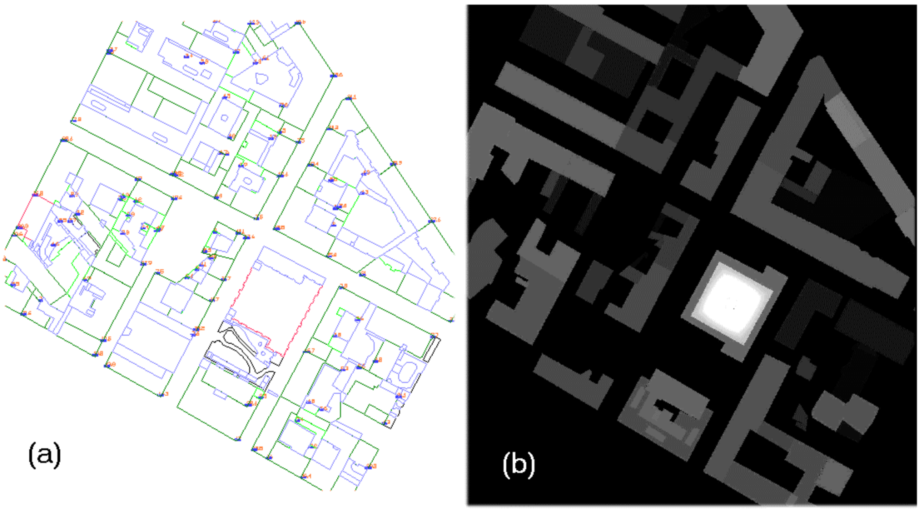


Figure 11: practical result of GeneDDEM

4. PRACTICAL TEST USING IKONOS IMAGES AND COMMERCIAL SOFTWARE

The effectiveness of such dense DEM on the obtainable planimetric accuracy of orthorectified aerial images has been already proved. We have applied this same technique to high resolution satellite images. According to the available images we had, the italian city of Livorno has been chosen as test site. The image is an IKONOS GEO-1 PAN product The test site area flat ground (terrain heights vary from 0 to 25 meters on the sea level) help us to better interpret the resulting differences in planimetric accuracy obtained orthorectifying with and without buildings height information. Its size is 4122x3910 pixels covering an urban area of about 4x4 km.

The lack of accurate information about attitude and position of the camera at the recording instant, and of the real scene geometry has driven us to carry out the test using a specific commercial software. We have promised to ourself to better analyze this problem in the future.

In order to take under control the cartographic instances and having no reliable information about how the commercial software works, it has been decided to perform cartographic transformation by ourselves. The digital cartography (DEM and vector cartography) in the Italian national GAUSS-BOAGA projection (Datum Roma40) has been transformed by a simple plane rototranslation with scale factor into the UTM zone 32N WGS84, the same in which orbital and geodata are given in the metadata and geotiff files of the IKONOS scene.

Using these data and with the limitations imposed by an approximate knowledge of the tool we have tried both to evaluate the commercial software itself and to determine the incidence of the use of a DDEM on high resolution satellite images. The software can operate in two different ways that permit to carry out an orthocorrection of IKONOS with and without ground Control Points (GCPs).

4.1 Test results obtained with a without GCP orthocorrection

In this modality the software uses only the IKONOS metadata and GEOTIFF files (orbital and attitude data, scene corner coordinates). Test have been made both with the use of a simple DEM (without buildings height information) and with a DDEM. Both DEM and DDEM have been derived from the same digital vectorial cartography scale 1:5000 used to collect GCPs and Check points. DEM has been generated by regularization and interpolation at the geometric resolution of the IKONOS PAN image (1 m) the irregular grid of height points coming from the correspondent layer of the .dxf file. DDEM has been generated as previously explained using a bilinear interpolation in an elaboration time of about 3.5 hours for 4500x4500 nodes. Figure 12 shows grey level images of the simple DEM and of the DDEM of the city of Livorno (ITALY).

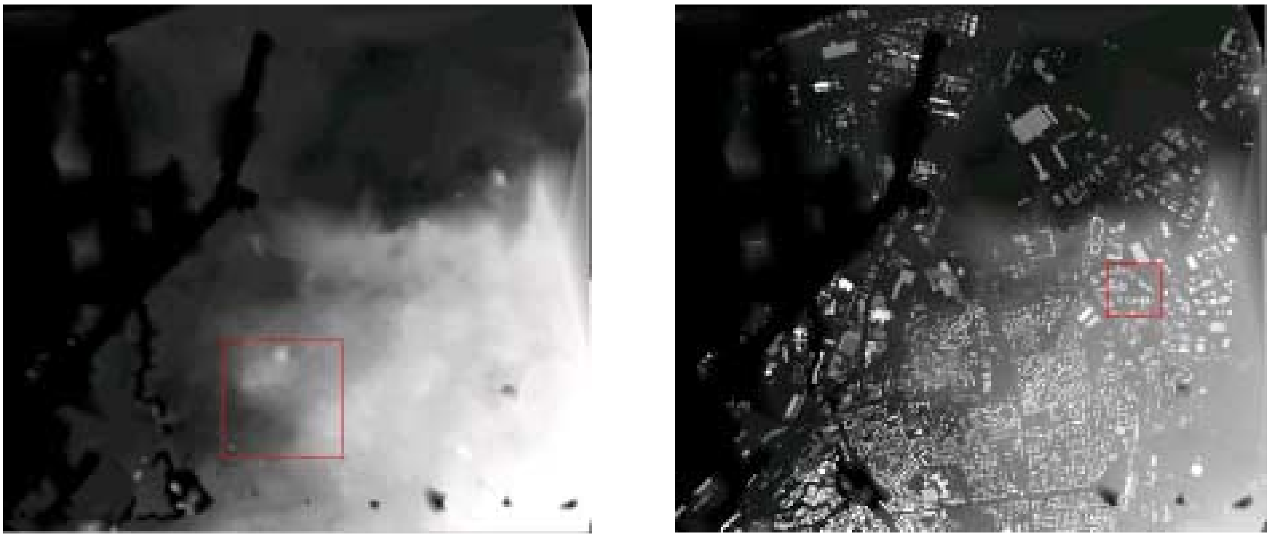


Figure 12: Simple DEM and DDEM of the city of Livorno (Italy) used during these tests.

Table1 shows some results referred to 20 Check Points collected on the with-no-GCP orthocorrected image based on the simple DEM. Table 2 shows some results referred to the previous same 20 checkpoints obtained by orthocorrecting with no GCPs and a DDEM.

ID point	cartography E	Cartography N	ortho E	ortho N	Δ E (m)	Δ N (m)	Δ tot (m)
1	606805,54	4824460,13	606804,50	4824457,50	1,04	2,63	2,83
2	607090,59	4824439,15	607085,50	4824437,50	5,09	1,65	5,35
3	607350,64	4824481,18	607350,50	4824480,50	0,14	0,68	0,69
4	607679,70	4824483,21	607679,50	4824482,50	0,20	0,71	0,74
5	607921,74	4824497,23	607923,50	4824495,50	-1,76	1,73	2,47
6	606908,58	4824203,09	606908,50	4824202,50	0,08	0,59	0,60
7	607339,65	4824253,14	607339,50	4824250,50	0,15	2,64	2,64
8	607580,71	4824165,14	607583,50	4824162,50	-2,79	2,64	3,84
9	607805,74	4824246,17	607805,50	4824246,50	0,24	-0,33	0,41
10	608056,79	4824219,19	608056,50	4824218,50	0,29	0,69	0,75
11	606909,61	4823856,03	606908,50	4823857,50	1,11	-1,47	1,84
12	607239,66	4823952,07	607239,50	4823948,50	0,16	3,57	3,57
13	607657,75	4823738,07	607657,50	4823736,50	0,25	1,57	1,59
14	607945,81	4823675,08	607946,50	4823674,50	-0,69	0,58	0,90
15	607743,77	4823715,07	607743,50	4823715,50	0,27	-0,43	0,51
16	606900,63	4823567,97	606899,50	4823566,50	1,13	1,47	1,85
17	607268,70	4823564,00	607263,50	4823564,50	5,20	-0,50	5,22
18	607464,73	4823570,02	607466,50	4823569,50	-1,77	0,52	1,84
19	607680,76	4823708,06	607682,50	4823706,50	-1,74	1,56	2,34
20	608039,84	4823583,07	608038,50	4823580,50	1,34	2,57	2,90
Mean	**Errors**				0,40	1,15	**2,14**
Mean	**Errors (ABS)**				1,27	1,43	
Max	**Errors (ABS)**				5,20	3,57	5,35
Min	**Errors (ABS)**				0,08	0,33	0,41
σ	**Errors**				1,96	1,29	**1,49**

Table 1: Check point discrepancies in the orthophoto (no GCP) generated using a simple DEM.

Check point							
ID point	Cartography E	Cartography N	ortho E	ortho N	Δ E (m)	Δ N (m)	Δ tot (m)
1	606805,54	4824460,13	606805,50	4824457,50	0,04	2,63	2,63
2	607090,59	4824439,15	607091,50	4824439,50	-0,91	-0,35	0,97
3	607350,64	4824481,18	607352,50	4824482,50	-1,86	-1,32	2,28
4	607679,70	4824483,21	607679,50	4824479,50	0,20	3,71	3,72
5	607921,74	4824497,23	607925,50	4824497,50	-3,76	-0,27	3,77
6	606908,58	4824203,09	606908,50	4824203,50	0,08	-0,41	0,42
7	607339,65	4824253,14	607339,50	4824253,50	0,15	-0,36	0,39
8	607580,71	4824165,14	607581,50	4824166,50	-0,79	-1,36	1,57
9	607805,74	4824246,17	607804,50	4824246,50	1,24	-0,33	1,28
10	608056,79	4824219,19	608057,50	4824219,50	-0,71	-0,31	0,77
11	606909,61	4823856,03	606909,50	4823856,50	0,11	-0,47	0,48
12	607239,66	4823952,07	607241,50	4823950,50	-1,84	1,57	2,42
13	607657,75	4823738,07	607660,50	4823738,50	-2,75	-0,43	2,78
14	607945,81	4823675,08	607947,50	4823675,50	-1,69	-0,42	1,74
15	607743,77	4823715,07	607744,50	4823715,50	-0,73	-0,43	0,85
16	606900,63	4823567,97	606900,50	4823567,50	0,13	0,47	0,49
17	607268,70	4823564,00	607270,50	4823564,50	-1,80	-0,50	1,87
18	607464,73	4823570,02	607466,50	4823569,50	-1,77	0,52	1,84
19	607680,76	4823708,06	607681,50	4823706,50	-0,74	1,56	1,73
20	608039,84	4823583,07	608040,50	4823582,50	-0,66	0,57	0,87
Mean	**Errors**				-0,90	0,20	**1,64**
Mean	**Errors (ABS)**				1,10	0,90	
Max	**Errors (ABS)**				3,76	3,71	3,77
Min	**Errors (ABS)**				0,04	0,27	0,39
σ	**Errors**				1,18	1,27	**1,04**

Table 2: Check point discrepancies in the orthophoto (no GCP) generated using a DDEM.

Results demonstrate the improvement in planimetric accuracy using a DDEM.

4.2 Test results obtained with a GCP-based orthocorrection

The effectiveness of the commercial software orthocorrection routines has been also tested in the second operational mode, that is defining 20 well spatially distributed GCPs. Planimetric accuracies have been computed referred to the GCP and to the same 20 Check Points of the previous tests, both for a simple DEM based orthocorrection (Table 3) and DDEM based one (Table 4). GCP accuracies are just summarized by some their statistical parameters.

GCPs							
ID point	cartography E	Cartography N	ortho E	ortho N	Δ E (m)	Δ N (m)	Δ tot (m)
Medium	**Errors**				0,28	-0,53	**1,12**
Medium	**Errors (ABS)**				0,70	0,65	
Max	**Errors (ABS)**				2,39	2,29	2,40
Min	**Errors (ABS)**				0,01	0,11	0,23
σ	**Errors**				0,90	0,73	**0,63**

Check Point							
ID point	cartography E	Cartography N	ortho E	ortho N	Δ E (m)	Δ N (m)	Δ tot (m)
1	606805,54	4824460,13	606806,50	4824458,50	0,96	-1,63	1,89
2	607090,59	4824439,15	607087,50	4824438,50	-3,09	-0,65	3,16
3	607350,64	4824481,18	607351,50	4824481,50	0,86	0,32	0,92
4	607679,70	4824483,21	607678,50	4824484,50	-1,20	1,29	1,76
5	607921,74	4824497,23	607922,50	4824497,50	0,76	0,27	0,81
6	606908,58	4824203,09	606908,50	4824204,50	-0,08	1,41	1,41
7	607339,65	4824253,14	607339,50	4824253,50	-0,15	0,36	0,39
8	607580,71	4824165,14	607582,50	4824164,50	1,79	-0,64	1,90
9	607805,74	4824246,17	607805,50	4824247,50	-0,24	1,33	1,35
10	608056,79	4824219,19	608056,50	4824219,50	-0,29	0,31	0,42
11	606909,61	4823856,03	606907,50	4823858,50	-2,11	2,47	3,25
12	607239,66	4823952,07	607237,50	4823950,50	-2,16	-1,57	2,67
13	607657,75	4823738,07	607656,50	4823737,50	-1,25	-0,57	1,37
14	607945,81	4823675,08	607942,50	4823675,50	-3,31	0,42	3,34
15	607743,77	4823715,07	607741,50	4823716,50	-2,27	1,43	2,68
16	606900,63	4823567,97	606899,50	4823570,50	-1,13	2,53	2,77
17	607268,70	4823564,00	607268,50	4823566,50	-0,20	2,50	2,51
18	607464,73	4823570,02	607463,50	4823570,50	-1,23	0,48	1,32
19	607680,76	4823708,06	607679,50	4823707,50	-1,26	-0,56	1,38
20	608039,84	4823583,07	608035,50	4823581,50	-4,34	-1,57	4,62
Medium	**Errors**				-1,00	0,40	**2,00**
Medium	**Errors (ABS)**				1,43	1,12	
Max	**Errors (ABS)**				4,34	2,53	4,62
Min	**Errors (ABS)**				0,08	0,27	0,39
σ	**Errors**				1,57	1,32	**1,10**

Table 3: Check point discrepancies in the orthophoto (with GCP) that is generated using a simple DEM

Results demonstrate how the mean accuracies and the statistical information are very similar to the without-GCPs case. The only remarkable difference is the errors standard deviations, which in the first case (with no GCP) is at least the 25% higher then in the second case. This points out that errors distribution is more uniform if GCPs are used, that is accuracy determination is more reliable. Two qualitative images (figure 13) showing the spatial distribution of planimetric errors (total) for both the DDEM orthoprojected with and without GCP image are presented below.

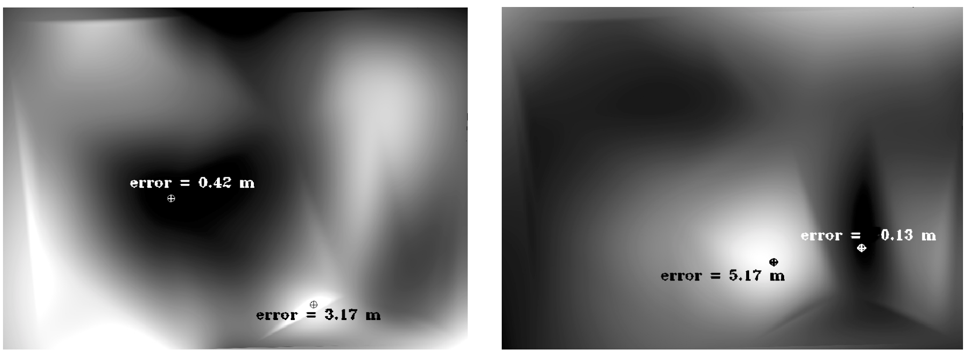


Figura 13: spatial distribution of planimetric total errors in the case of with-GCPs DDEM orthocorrection (left) and in the case of without-GCPs DDEM orthocorrection (right).

Their difference is mainly represented by the anomalous error concentration in the case of no GCP orthocorrection. Some further investigations should be done in order to understand this phenomenon better.

GCPs							
Mean	**Errors**				0,68	-0,73	**1,59**
Mean	**Errors (ABS)**				1,06	1,05	
Max	**Errors (ABS)**				2,39	2,29	2,69
Min	**Errors (ABS)**				0,01	0,13	0,23
σ	**Errors**				1,12	1,01	**0,80**

ABS=module

Check point							
ID point	cartography E	Cartography N	ortho E	ortho N	Δ E (m)	Δ N (m)	Δ tot (m)
1	606805,54	4824460,13	606806,50	4824459,50	0,96	-0,63	1,15
2	607090,59	4824439,15	607088,50	4824438,50	-2,09	-0,65	2,19
3	607350,64	4824481,18	607350,50	4824481,50	-0,14	0,32	0,35
4	607679,70	4824483,21	607680,50	4824483,50	0,80	0,29	0,85
5	607921,74	4824497,23	607921,50	4824496,50	-0,24	-0,73	0,77
6	606908,58	4824203,09	606909,50	4824204,50	0,92	1,41	1,68
7	607339,65	4824253,14	607339,50	4824254,50	-0,15	1,36	1,37
8	607580,71	4824165,14	607581,50	4824164,50	0,79	-0,64	1,02
9	607805,74	4824246,17	607805,50	4824248,50	-0,24	2,33	2,34
10	608056,79	4824219,19	608055,50	4824219,50	-1,29	0,31	1,33
11	606909,61	4823856,03	606908,50	4823858,50	-1,11	2,47	2,71
12	607239,66	4823952,07	607239,50	4823952,50	-0,16	0,43	0,46
13	607657,75	4823738,07	607655,50	4823738,50	-2,25	0,43	2,29
14	607945,81	4823675,08	607944,50	4823675,50	-1,31	0,42	1,38
15	607743,77	4823715,07	607742,50	4823716,50	-1,27	1,43	1,91
16	606900,63	4823567,97	606898,50	4823569,50	-2,13	1,53	2,62
17	607268,70	4823564,00	607269,50	4823566,50	0,80	2,50	2,62
18	607464,73	4823570,02	607463,50	4823570,00	-1,23	-0,02	1,23
19	607680,76	4823708,06	607678,50	4823709,50	-2,26	1,44	2,68
20	608039,84	4823583,07	608037,50	4823584,50	-2,34	1,43	2,74
Mean	**Errors**				-0,70	0,77	**1,68**
Mean	**Errors (ABS)**				1,12	1,04	
Max	**Errors (ABS)**				2,34	2,50	2,74
Min	**Errors (ABS)**				0,14	0,02	0,35
σ	**Errors**				1,18	1,05	**0,80**

Table4: Check point discrepancies in the orthophoto (with GCP) that is generated using a DDEM.

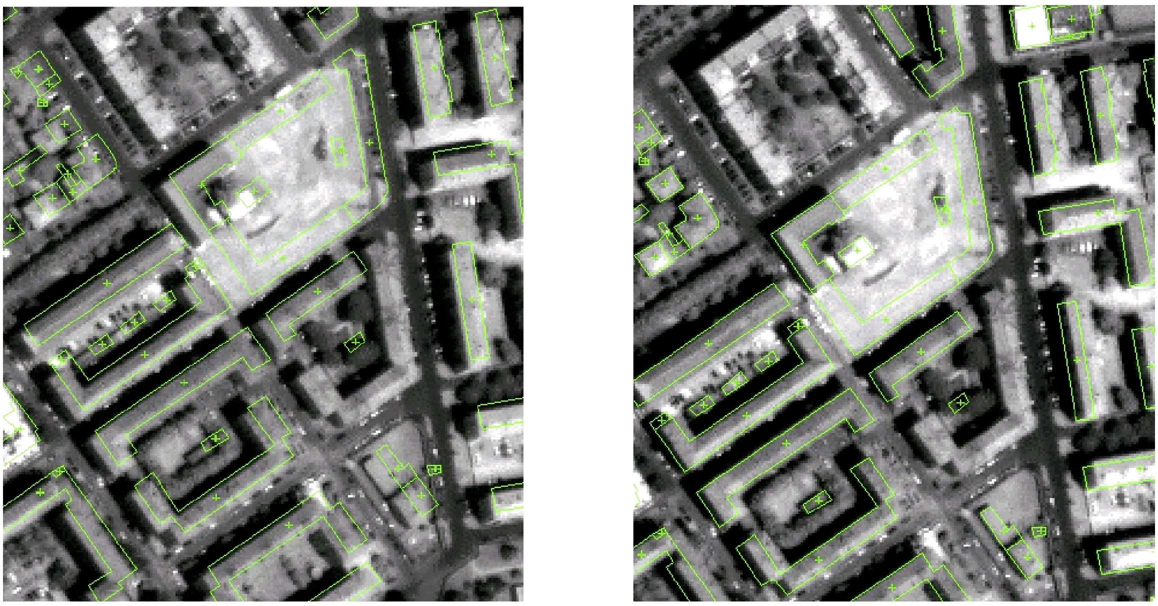


Figure 14: Before (left) and after (right) DDEM orthocorrection numerical WGS 84 32N cartography image (portion) overlaying.

These last two images (figure 14) show the evident improvement in the image geocoding after orthoprojection. The overlaid cartography is now well fitting the buildings on the image showing the real incidence of the DDEM. Attention should be paid to the apparent dislocation of cartography respect to some buildings. But they simply result from the non-nadiral perspective of the scene. Cartography now quite well fits the building foot which, due to non-nadiral perspective, is displaced from the roof top borders.

5. CONCLUSIONS

The integration of digital images in GIS ambient is needed in the field of some application (engineering, environmental, geology, etc.). The digital orthoprojection is a fundamental tool to realize this integration in a correct metrical way, but requires particular consideration for urban areas application. In this case, a rigorous digital orthophotos can be correctly produced using a dense DEM that can be generated by means of 3D digital cartography and high resolution image acquired by satellite platform.

Some practical tests show this possibility evaluating a metrical accuracy comparable with the tolerance required for medium digital cartography production.

Due to the black-box approach to the use of the commercial software for the orthocorrection we can only underlined that surprisingly accuracies obtained with and without GCP are comparable. That drive us to consider that the metadata supplied with the original geocoded IKONOS image and the image itself are quite well defined. Some further tests shoul be done in order to rigorously demonstrate that.

REFERENCES

1. H. Mitasova, J. Hofierka, “Interpolation by regularized spline with tension; Part I, Theory and implementation”, *Mathematical Geology* **25**, pp. 641-655, 1993
2. H. Mitasova, J. Hofierka, “Interpolation by regularized spline with tension; Part II, Application to terrain modelling and surface analysis”, *Mathematical Geology* **25**, pp. 657-667, 1993
3. S. Mallat, *A wavelet tour of signal processing*, Academic press, 1998
4. Amhar, F., Ecker R., “An integrated solution for the problems of 3D man-made objects in digital orthophotos” *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXI, Part B4, 1996
5. Krauss K., *Photogrammetry, Volume 2*, Dümmler Verlag, 1997