TRUE ORTHOPHOTO OF THE WHOLE TOWN OF TURIN

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ABSTRACT:

The wide diffusion of modern GIS/LIS instruments requires new geomatical techniques that allow also to unskilled operators the use of such powerful tools. Digital orthophoto is a cheap and efficient product able to integrate GIS/LIS applications with a rigorous photographic representation of urban areas.
In large-scale mapping applications, especially where complex architectural objects have to be represented, the problem becomes complicated because there are many discontinuity lines (break-lines) and hidden areas. This requires a more sophisticated orthoprojection procedure, called “true orthophoto”.
In recent years, the authors have developed and presented (CIPA, 2001) an original procedure to produce true orthophotos using a “dense DEM” (DDEM) and all the images available in the photogrammetric block (“multi-image” procedure). A software package able to resolve this purpose has been implemented in Visual Fortran and optimised for practical mapping application. It consists in two modules:

- ACCORTHO (=ACCurate ORTHOphoto), to produce rigorous digital orthophotos starting from multiple images and a DDEM;
- GENEDDEM (GENEration of a DDEM), able to build a dense DEM (suitable for ACCORTHO) from a 3D digital map, using sophisticated interpolation techniques.

This paper describes in detail the structure of the GENEDDEM and a practical application of both the programmes for a relevant mapping project, that is still in progress: a true orthophoto of the whole town of Torino (about 5000 ha), in scale 1:2.000, containing many complex architectural objects (Mole Antonelliana, the Gran Madre Church, the Holy Shroud Cathedral).

1. INTRODUCTION

The diffusion of technologies inherent to Geographic Information Systems (GIS), especially in urban areas, has led to new instruments for the solution of a series of problems connected to new duties that municipality administrations have to perform: the necessity, established by law, of rationalising the competences of the various territorial organisations in a cartographic ambit and the production of suitable instruments to interchange geographic information.
GIS at a local scale require representations of the municipality territory in a large-scale digital map, often in three-dimensional form (3D).
The digital orthophoto constitutes an efficient and low-cost product that can be used to complete the contents of a GIS with a both metric and photographic representation of the territory, that helps inexperienced users in interpreting the territorial objects. The geometry of this particular photographic map is obtained through the orthogonal projection of each pixel of the image, representing whether natural or man-made objects, onto the cartographic plane in such a way that the original prospective representation, such as the aerial photograph, is transformed into an equivalent image, metrically correct: measuring co-ordinates, angles, distances, areas on the orthophoto gives correct results, exactly as on a map.
If the surface of the territory is continuous (smooth) it can be efficiently described using a regular grid (DEM) of the assigned points in which the sides of the mesh have dimensions that vary from 5 to 50 m according to the representation scale (usually 1/200 of the scale denominator).
In this case it is very easy to make the orthophoto: numerous adequate commercial software programs are available that can guarantee acceptable precision in line with the relative cartographic tolerances. Unfortunately, continuity does not exist in urban centres: a surface that is covered by artificial objects (buildings, infrastructures, bridges, etc.) is surely not smooth and cannot therefore be modelled with a classical DEM. In these cases, it is necessary to use more refined solutions. The authors [Dequal, Lingua, 2001] have recently proposed and practically developed a procedure for accurate orthoprojection (ACCORTHO) that is based on a “dense DEM” (called DDEM = Dense Digital Elevation Model) and which is developed in Visual FORTRAN language.
The Municipality of Turin, in collaboration with CSI-Piemonte, falls into this context in the ambit of development programmes of its GIS (which is made up on a digital cartographic base in a 1:1000 scale). The Municipality saw the opportunity of integrating this instrument with digital colour orthophotos of the territory and drew up a research contract with the Geo-resources and Land Department of the Politecnico di Torino. This project, of remarkable dimensions (the territory belonging to the municipality covers about 12.000 hectares) has led to a further development of the ACCORTHO software through a series of interventions that were made to improve the

performances and the user interface and to make it suitable for a productive context.

The main developments of the software that concern the adaptation of the program to the quality of the data that have to be processed, the development of a routine set to help in the production, the adoption of optimised solutions to automate the process and the setting up of the user interface in Windows are here described.

2. GENERATION OF A DDEM FROM A 3D MAP

It is by now known [Boccardo et al., 2001] that two series of initial data are necessary to produce a true digital orthophoto:

- a set of digital images with known internal and external orientation parameters (obtained through bundle block adjustment or through direct methods based on GPS/INS integrated sensors) so as to guarantee the most complete photographic coverage of the territory as possible;

- the correct description of the surfaces that can be obtained, alternatively, through a traditional DEM, complete with break-lines, a digital surface model (DSM) composed of surface geometric primitives or a dense DEM (DDEM):

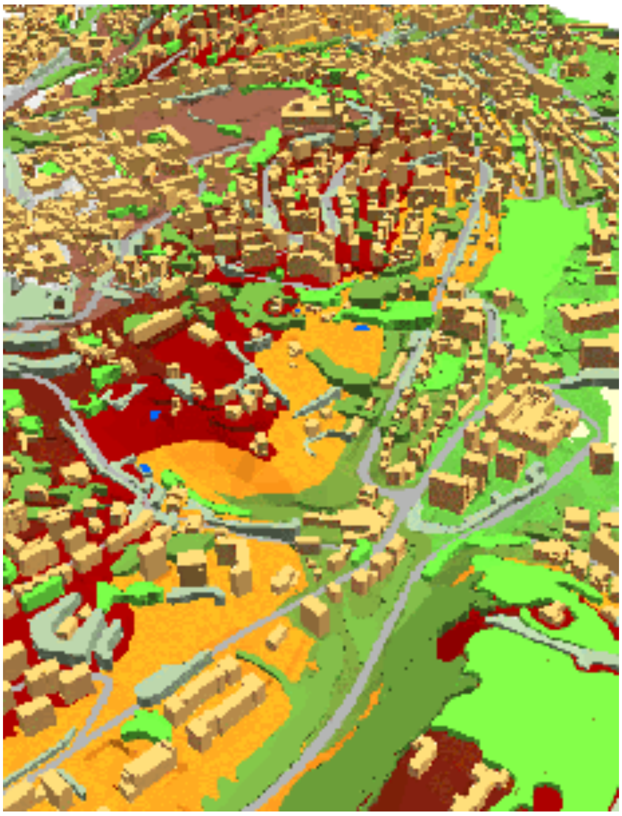

Figure 1. An example of 3D digital cartography

This latter is often the easiest and cheapest solution to operate. It in fact does not require heavy restitution or editing operations, it does not use sophisticated software based on the management of complex relational and logical databases, and it can easily be acquired using modern instruments (laser scanners) or, in a cheaper way, using interpolation from 3D maps, whenever they already exist. It should be considered that this cartography is increasingly available in most of the towns, both as a cartographic base for urban planning and as a geometric base for local GIS. A 3D digital cartography describes the territory and buildings in planimetry and heights and therefore contains all the information that is necessary to generate the corresponding DDEM:

- the natural ground surface is described through spot heights and contour lines;

- artificial objects are represented through vertices known in the 3 co-ordinates (roads, bridges, and railways are described by polylines whose vertices are known in XYZ);

- buildings are described as distinct volumes of equal height, on whose inside a spot height ("centroid") is associated. In this way, buildings can resemble to solid shapes (whose base is the boundary of the building) extruded out of the terrain up to the height of the associated centroid.

An example of 3D cartographic elements is given in figure 1 [Spalla, 2002]

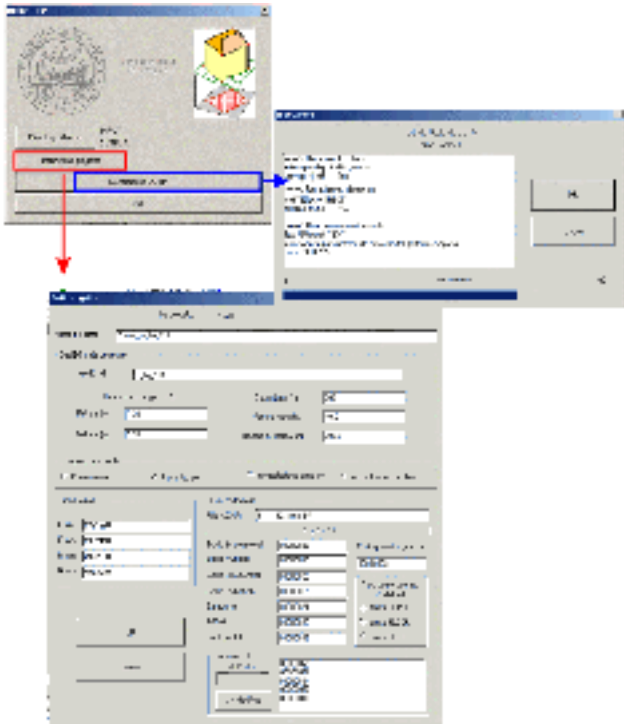

Figure 2. Some of the user interface windows

2.1. The GeneDDEM software

The GENEDDEM software, which has been developed in Visual FORTRAN language, uses the information that derives from a digital map to generate a dense DEM of the territory. The input data that are necessary are those that are found (or that have to be integrated) in a 3D digital map in DXF format, with the description of the geometry (in which all the areas are described by closed 3D polylines) and a list of the codes inherent to spot heights, contour lines, various types of

buildings (monumental, public, residential, industrial, sheds, roofs, covered tunnels etc.,), and other types of areas that have to be processed (roads, green areas, water, yards, slopes. sports areas, cemeteries, etc.). Some of the graphic interface windows are shown in fig. 2 (the main, data input and processing windows).
GENEDDEM works in 3 stages (as shown in fig. 3) which are indicated in the processing window with a progression bar (see fig. 2):

- filling the areas inherent to the buildings with their heights: extraction of the DXF file of the centroids, reading of the various polylines in sequence with the code corresponding to a building object, filling of all the DDEM grid points inside the boundary of the building;

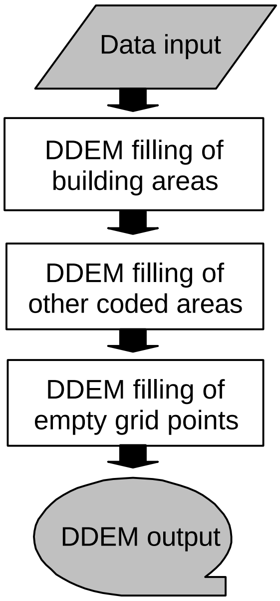

Figure 3 - Flow chart of GENEDDEM

- filling of other areas: extraction of the DXF file of spot heights and contour lines, reading of the polylines in sequence with the corresponding code of the entity, search for the points that are inside the area, interpolation of the height of the grid points inside the considered area on the basis of the height points and the vertices of the boundary polylines;

- filling of the remaining part of the DDEM (natural ground).

The file that contains the complete DDEM is then stored in binary form. A description file contains the number of lines and columns of the DDEM, the reference system and the step of the grid so as to make it directly usable by the ACCORTHO module or by one of the many commercial packages available on the market, suitable for digital image processing (for ex.: ENVI). The interpolation techniques that have been implemented in the ACCORTHO package are in short: closest points, minimum square planes, bilinear and bicubic splines [Brovelli, 2002].
An example of the results of the GENEDDEM software can be seen in fig. 4: a portion of the 3D map in scale 1:1000 of the Municipality of Turin (map no. 112) is shown in part (a), the display of the derived DDEM (with a step of 20 cm, which is suitable for orthophotos in scale 1:2.000), is represented in part (b) as an image where a grey scale corresponds to the heights.
The processing time required about 1 hours (for the entire sheet of 6600x5500 points, interpolated by bilinear splines), using a standard PC equipped with a Pentium IV (1,5 GHz - 512 Mb RAM).

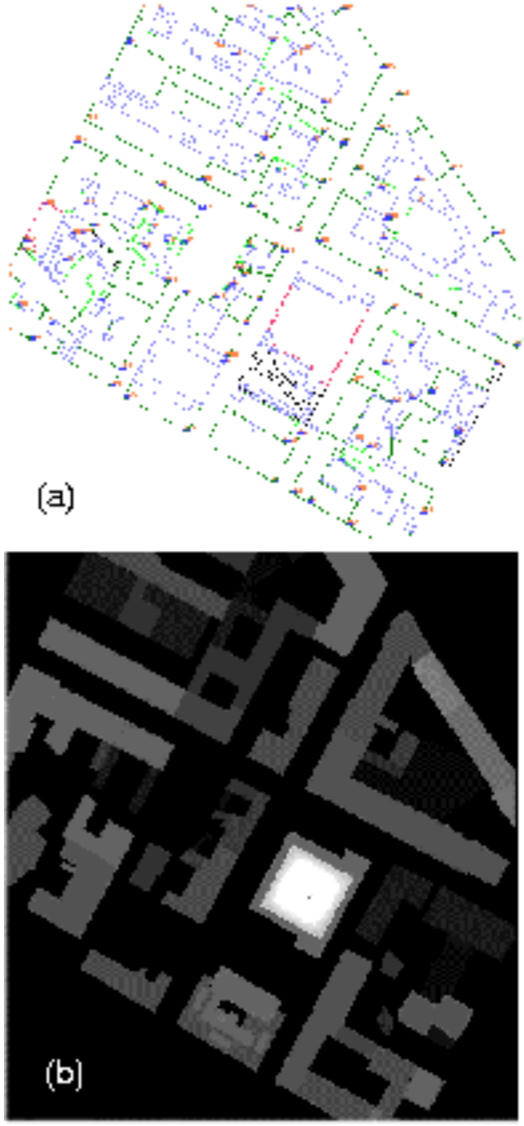

Figure 4 - An example of an elaboration with GeneDDEM: (a) digital cartography, (b) grey-level image of DDEM

3. EVOLUTION OF THE ACCORTHO MODULE

Concepts and algorithms of the ACCORTHO module have remained basically the same as the first version [Boccardo et al., 2001]. The changes that have been implemented in the last year refer to the operative and optimisation problems with the purpose of making the software suitable for a massive production.
In short, the main changes that have been made are:

- the final image of the orthophoto is made up of small portions so as to optimise the production process of large orthophotos: it should be recalled that a colour orthophoto of a map sheet in 1:2.000 scale (standard size) with ground pixels of 20 cm (~ 300 dpi) is made up of about 105 Mbytes (about 6600 x 5500 pixels);

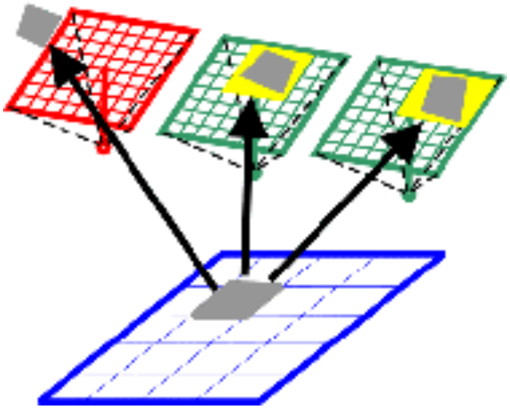

Figure 5. Window to choose the images of the block

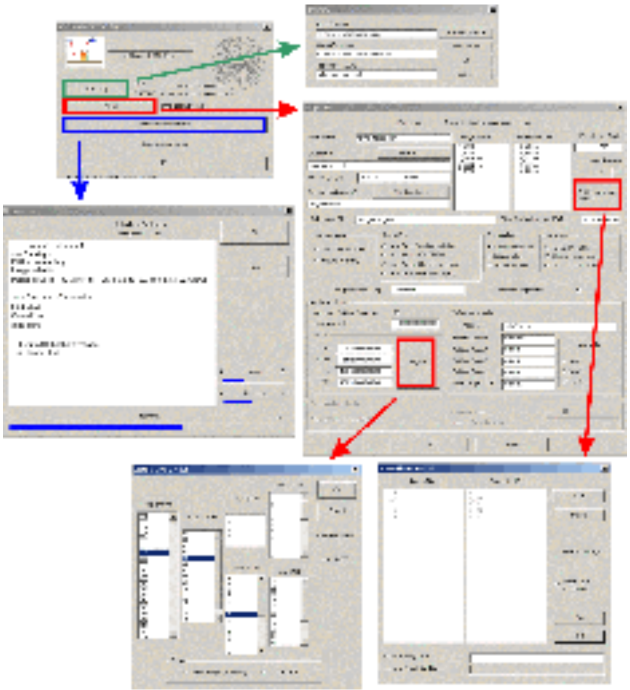

Figure 6. Some user interface windows

- the orthoprojection procedure allows the extraction of the available images in which each above mentioned portion has been identified (see fig. 5): in this way, the loading operations of the input images are limited, considering that there are a maximum of 6 images of interest;

- the layout of the orthophoto can be defined on the basis of the standardised map-sheet format for the technical large scale cartography: the operator chooses only the scale and the considered sheet and then the software determines the co-ordinates of the 4 vertices of the map. The pixels that fall outside the sheet format are forced to be white in the final orthophoto;

- the software generates a georeferenced digital image that can immediately be loaded and used in a GIS;

- the user interface was completely rethought up, taking advantage of the possibilities offered by Visual FORTRAN language in a Windows environment. The main window, two data input windows, the window inherent to the cartographic format and the processing stage can be seen in fig. 6.

Figure 7. Images extracted from aerial photos of Mole Antonelliana (a) and the Gran Madre Church (b)

5. TRUE ORTHOPHOTO OF THE CITY OF TURIN

The Municipality of Turin decided to integrate its GIS with a true orthophoto of the whole territory.
For this reason it ordered a colour photo flight at a scale of about 1:5.000, which is also adequate to update its digital map in scale 1:1000. The images were oriented using a bundle block adjustment. The photos were later acquired using a photo

scanner with a resolution of 600 dpi (mean pixel at the ground of 20 cm) so as to allow the production of the orthophoto in a scale of 1:2000.

The digital map has been integrated, by CSI-Piemonte, with some heights that were not originally present (bridges, new buildings, …): an example of the result can be seen in fig. 4a. The production of the orthophoto required a preliminary setting up, which allowed the previously described developments to be made to the software and to test it on a test field (18 maps for about 2000 ha). This test field was particularly critical as it includes: the dense built up area of the historical centre of the town, monumental buildings such as the Mole Antonelliana and the Gran Madre Church (see fig. 7), bridges over the Po and Dora rivers and the residential area in the Turin hills.

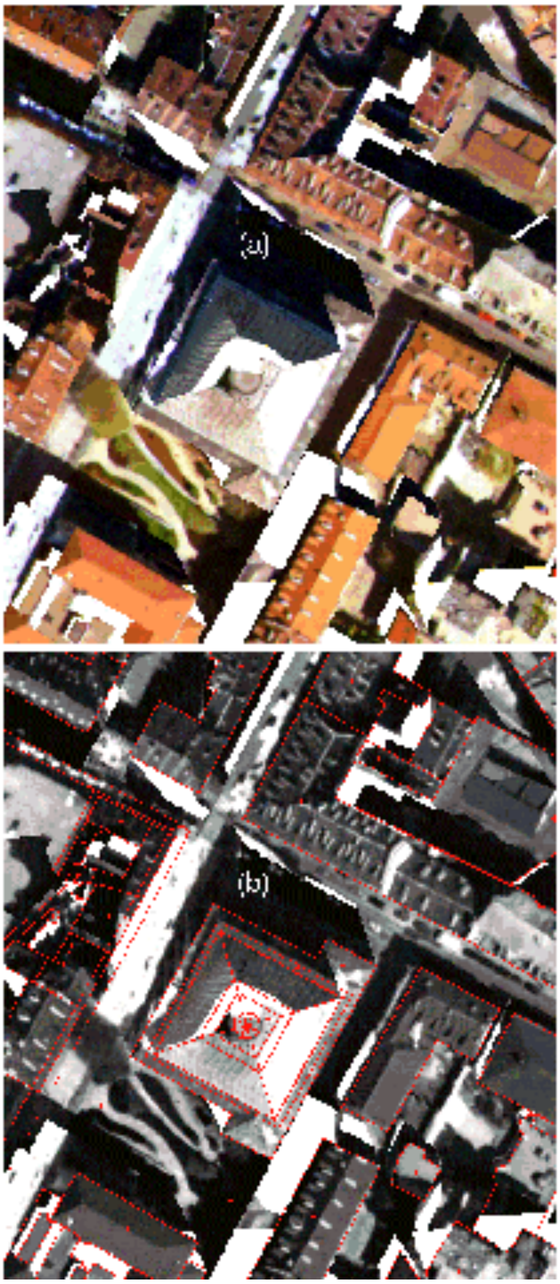

Figure 8. The true orthophoto of the Mole Antonelliana (a) and its superimposition to the map (b).

A prototype (greatly enlarged) of what was obtained in correspondence to the Mole Antonelliana (a) and its superimposition to the map of the same area (b) are shown in fig. 8. In similar complex cases, it is necessary to integrate the already existing digital map with an *ad hoc* restitution of some missing elements of the monumental structure so that the DDEM describes it faithfully (see fig. 9). The resulting correct orthoprojection and the perfect adherence with the map can be noted, these being results that could never have been obtained with conventional orthoprojection such as that available from any commercial software that can be found on the market.
Other significant examples (the Gran Madre Church and the Holy Shroud Cathedral) are shown in fig. 10.

Figure 9 - Integration of the already existing map with the resti-tution of some relevant elements of the Gran Madre Church

6. CONCLUSIONS

The true digital orthophoto is a product that is particularly suitable for the representation of urban areas by large scale maps and it is an important instrument for the integration of the practical aspects of GIS/LIS in a municipal environment. The generation of the DDEM through the use of already existing 3D digital cartography leads to a reduction of the production costs of the orthophoto, making it necessary to restitute only some monumental and new buildings. The ACCORTHO software, integrated with the GENEDDEM module, after the modifications that have here been described, allows true orthophotos to be produced in a quick and cheap way with a high degree of automation.

Figure 10 - True orthophotos of : (a) Gran Madre Church, (b) Holy Shroud Cathedral and Royal Palace

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