

A NEW PROCEDURE FOR THE AUTOMATIC PRODUCTION OF TRUE ORTHOPHOTOS

Andrea Biasion (*), Sergio Dequal (*), Andrea Lingua (*)

(*) Politecnico di Torino – Dipartimento di Georisorse e Territorio
 Corso Duca degli Abruzzi, 24 – 10129 Torino – Italy

Email: andrea.biasion@polito.it, andrea.lingua@polito.it, sergio.dequal@polito.it

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ABSTRACT:

The digital orthophoto is a cheap and efficient product that is used to represent the correct shape of any 3D object, in photographic form, by means of its orthogonal projection onto a predefined plane. In mapping applications, if the zone to be represented contains urban areas, the problem becomes more complex because there are many discontinuity lines (breaklines) and hidden areas: this requires a more sophisticated orthoprojection procedure. The lack of information corresponding to the hidden areas is avoided if use is made of all the images (“multi-image” procedure) available in the photogrammetric block. More rigorous interpolation methods should be used to take into account the problem of discontinuities. Stereoplotting of the many break-lines (a difficult and expensive procedure) or, even, a DTM formed by a large amount of points (the so-called “dense DTM”, or DDTM) gives the necessary data. For this purpose, the authors have recently conceived and implemented an original software composed of the following modules:

- AccOrtho (=ACCurate ORTHOphoto), to produce rigorous digital orthophotos starting from multiple images and a DDTM;
- GeneDDTM (GENeration of a DDTM), which is able to build a dense DTM (suitable for AccOrtho) from a 3D digital map, using sophisticated interpolation techniques.

This paper describes the two software structures in detail and a practical application of both the programmes for a relevant mapping project, which is still in progress: a true orthophoto of the whole town of Turin, in 1:2.000 scale.

1. INTRODUCTION

An orthophoto is a metrically correct photographic representation of the territory, with the same accuracy as a traditional topographic map. It also contains a great deal of information that is not present in a topographic map, such as the details that are present in aerial photos. The natural or antropized territory is represented as it really appears, without the introduction of codes or symbology as used in digital map production. An unskilled user can understand and correctly read an orthophoto, while the correct interpretation of a digital map requires a specific technical background.

The geometry of this particular photographic cartography is obtained by orthogonal projection of each pixel of an aerial image onto a cartographic plane. In this way, the original perspective representation, as an aerial photo, is transformed into an equivalent metrically correct image: it is possible to measure angles and distances (in a known scale factor) and read coordinates on the orthophoto, exactly like on a traditional map. An orthophoto can be employed in several land planning applications (infrastructural planning, land use monitoring, i.e.). In an urban context, where the land surfaces are characterized by many discontinuities and hidden areas, there can be some problems with commercial software.

It is necessary to use a specific procedure for the automatic production of a true and rigorous orthophoto [Dequal et al., 2002].

2. TRUE ORTHOPHOTO OF A DISCONTINUOUS SURFACE

The case of a DTM (see figure 1) that, only correctly describes the ground, and not the existing buildings, is considered. The projection of point Q originated an uncorrect location of point Q_0' , instead of the right position of Q_0 that also coincides with orthoprojection P_0 of point P. Figure 1 shows this effect: the base of the building is represented in the right position, while the roof is moved to an incorrect position.

Let us now consider the case in which the building is also described by the DTM (figure 2). Point Q is represented

correctly by Q_0 but, if a traditional orthoprojection is used, point P is lost (hidden by point Q due to the geometry of the projection) and is substituted by the visible point Q which is doubled (in P_0) on the resulting orthophoto.

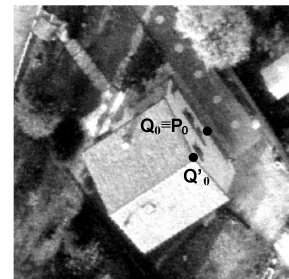
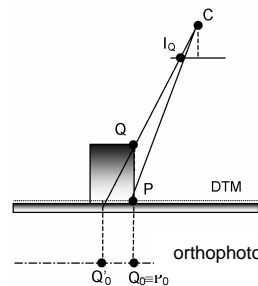


Figure 1: Orthoprojection with an erroneous description of the shape

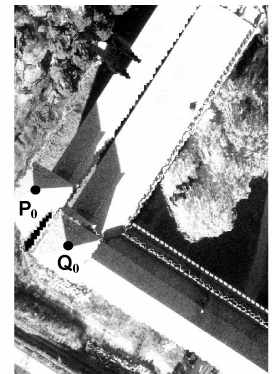
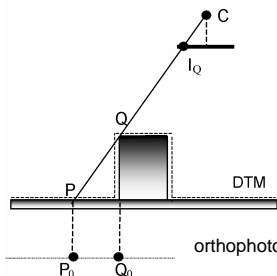


Figure 2: Orthoprojection with hidden areas

The image of the hidden area is not available on the considered photo, and should be extracted from other photos (when available). The doubled image however leads to confusion, and is obviously undesirable. If these two effects are considered,

we can say that, to generate a rigorous and complete orthophoto of a discontinuous surface the following are required:

- the correct description of the surface;
- the availability of images that represent all the details of the object.

If several different prospective images are available using all the projection rays for each point (as shown in fig. 3), some precautions have to be taken, to avoid doubling the images. For example, point Q_0 has to be obtained from image I_Q and point P_0 from I_P .

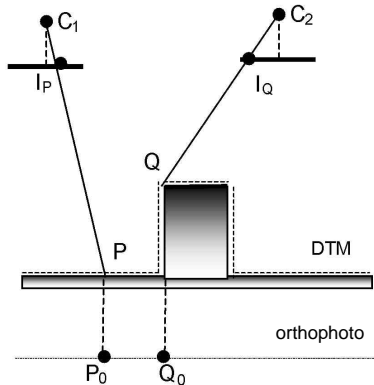


Figure 3: True Orthoprojection from multiple images

3. DDTM GENERATION FROM A 3D MAP

It is already known [Dequal et al., 2001], that, to produce a complete true orthophoto of a discontinuous surface, two starting data sets are necessary:

- a set of digital images with known interior and exterior orientation parameters (obtained by aerial triangulation, or by direct methods with GPS/INS sensors), to guarantee a photographic cover of the territory that is as complete as possible;
- the correct description of the surface, obtained, alternatively, by:
 - a traditional DTM, completed with breaklines;
 - a digital surface model (DSM), that contains superficial geometric entities, managed by complex database logics.
 - a dense DTM (DDTM).

The latter is usually the cheapest and simplest solution. It does not require expensive stereoplottling and editing operations or complex data base management software: it can easily be acquired with modern instruments (laser scanner), or in a cheaper way, with interpolation from a 3D digital map, whenever it exists. This kind of cartography moreover is becoming very common in local municipality administrations, as a base map for urban development instruments, and as a geometric base for Geographical Information Systems. A 3D digital map describes the territory and buildings in a tridimensional space and therefore contains all the information needed to generate the corresponding DDTM:

- a surface without buildings is described with height points and contour lines;
- each area is represented with points known in the 3D coordinates (streets, bridges, and railways are described with arcs and nodes, whose points are known in X, Y and Z coordinates)
- buildings are described as volumetric entities, of uniform height, with a central height point. In this way, the volumetric entities can be compared to parallelepiped shapes (with the building perimeter as

the base), extruded from the ground in a vertical direction, up to their height.

An example of 3D cartographic representation is shown in figure 4.

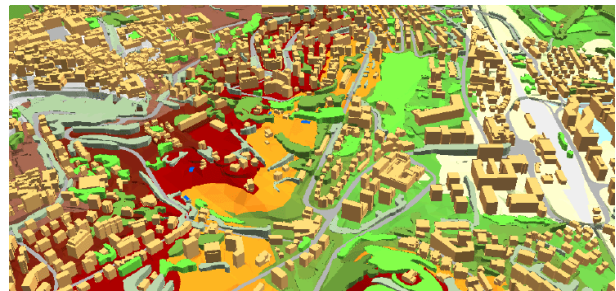


Figure 4: An example of 3D digital cartography [Spalla, 2002]

3.1 GENEDDTM software

The GeneDDTM software, developed in Visual Fortran language by the authors, uses information from the digital map to generate a dense DTM of the corresponding zone. The necessary input data are contained in a DXF format file of a 3D digital map, with the description of the geometry (with all the areas described as 3D closed polylines) and a code directory concerning the height points, contour lines, the different kinds of buildings (monumental, public, residential, industrial, and so on), building height points, and the different kinds of areas that have to be processed (street arcs and nodes, green areas, playgrounds, cemeteries, and so on). Some dialogue windows are shown in fig. 5 (the main one, data entry, and processing windows).

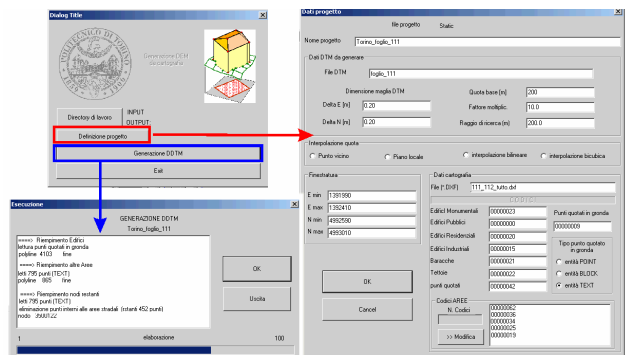


Figure 5: Some dialogue windows of the GeneDDTM software

GeneDDTM works in four separate phases, which are displayed in the dialogue window with a progression bar (as shown in fig. 5):

1. Filling of the areas inherent to the buildings with their heights, extraction of the height points from the DXF file (group n°1), sequential access to all the polylines with a building code, search inside group n. 1 of each corresponding height point, giving the same height to each node inside the single area.
2. Filling of the other areas: extraction of the height points from the DXF file and the points that describe the contour lines (group n. 2), sequential reading of the polylines with a code that corresponds to the aerial entities, search for the points in group n. 2 inside the area (group n. 3); interpolation of the height of the DDTM inside the considered areas based on points from group n. 3 and on the points of the polyline.

- Filling the remaining part of the DDTM (ground), with interpolation based on points of group n. 2 from which the points inside the areas processed in the previous step will be removed. In this way the interpolated surface also follows the ground even when there are bridges and similar infrastructures.
- Binary format writing of the DDTM file (each height is an integer number). A file is also compiled, that contains a description of the number of columns and rows, the reference system, the step, the multiplying factor to use the AccOrtho software or any other commercial image elaboration software (ENVI, e.g.).

In short, the interpolation techniques implemented in the software are: Nearest Neighbor, Mean Square Plane, Bicubic and Bilinear Spline [Brovelli, 2001].

An example of the output result of the GeneDDTM software can be seen in fig. 6. The first part (a) contains a portion of 3D base map at 1:1000 scale of the city of Turin (map sheet n° 112). The second part (b) contains a digital grey scale image of the corresponding DDTM (with pixel size of 20x20 cm², which is suitable for a 1:2000 scale orthophoto), generated with GeneDDTM in a processing time of about 30 minutes (for the entire 2300x3400 node sheet, using a bilinear spline) on a standard Pentium 4 1.5 GHz PC – 512 Mb Ram.

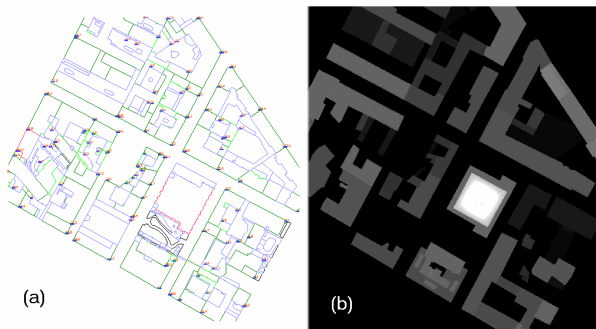


Figure 6: a result obtained with the GeneDDTM software

4. HOW TO PRODUCE AN ACCURATE ORTOPHOTO

In 1996 Amhar and Ecker proposed an original solution for the generation of a true orthophoto. The procedure, devoted to the production of orthophotos in urban areas, used a DSM that was managed by a relational database. All the images were classified as terrain or building surfaces and the orthophoto was generated in separate phases: first the terrain then the roofs. The results of these treatments were then merged into a single digital orthophoto. Hidden areas were eliminated through superimposition of the orthophoto generated from other images. The proposed solution tries to simplify this approach. The input data for the generation of a true orthophoto are: a DDTM as previously described, and a series of oriented images containing the radiometric description of all the points to be orthoprojected. The aims of the procedure are: to maintain complete automation so as to guarantee the same performances as a traditional orthoprojection software and to avoid the previously highlighted problems.

Let us consider the object in figure 7. In perspective images, higher points correspond to lower points, therefore the procedure must run from the highest to the lowest point.

The procedure starts from point R. The best recording of the grey value of this point can be found in the image which has the projection centre nearest to the point itself (image I1). In order to avoid the duplication of the images (as see in fig. 2), this pixel should be inhibited: for this reason a “flag image” is created where each pixel records the height used for the

orthoprojection of the corresponding pixel on the original image. Point R has also been recorded in I2 and, for the same reason, the pixel that represents point R on I2 should also be inhibited.

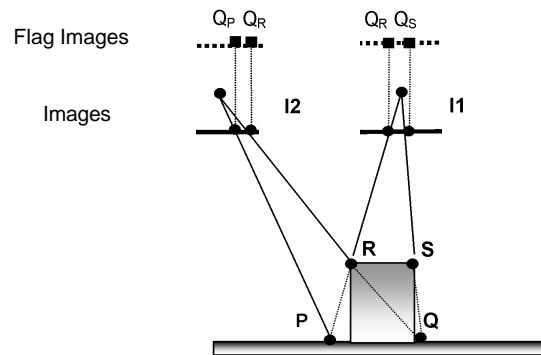


Figure 7: Ortoprojection procedure scheme

The procedure orthoprojects point S with the same criteria (point S will only be recorded in I1). When the procedure orthoprojects point P, it finds the pixel on I1 that was used before for point R. The flag image inhibits a second use of this pixel, because the height recorded on it is higher than the height of point P. Then the procedure looks for the grey (or colour) value in I2. The pixel is not inhibited and the orthoprojection of point P is possible. When the procedure orthoprojects point Q, the first attempt is to use the corresponding pixel on I1, but this pixel has been used for point S and the “flag image” then inhibits the radiometric value reading. The second attempt is to use the corresponding pixel on I2, but also this pixel has been inhibited because it contains the grey (or colour) value of point R. In this case, no more images being available, the orthoprojection of point Q cannot be defined. This simple example describes all the possible cases of a true orthophoto projection.

5. ACCORTHO SOFTWARE

The procedure that is described in the previous section was implemented in a specific software called ACCORTHO (ACCurate ORTHOprojection).

The input data consist of a regular DDTM, generated as previously described.

The software works in two separate steps. In the first, it selects and prepares the data. In particular it:

- calculates the heights of each pixel of the output image (a true orthophoto) and orders the pixels according to decreasing heights;
- extracts the portions of the digital images involved in the orthoprojection;
- prepares an index of the images in order to find the radiometric value to use whenever possible. The images are ordered on the basis of the distance between the projection centre and the considered pixel;
- generates an empty flag image for each input image.

The second step of the procedure puts the process described in the previous section into practise. Fig. 8 shows the flow chart of the basic functions.

The functioning of the AccOrtho software has remained unchanged since it was first released [Dequal et al., 2001]. The evolutions that have been implemented in the last year concern some optimization and operative problems, and they have been

made to transfer the procedures to a production environment.

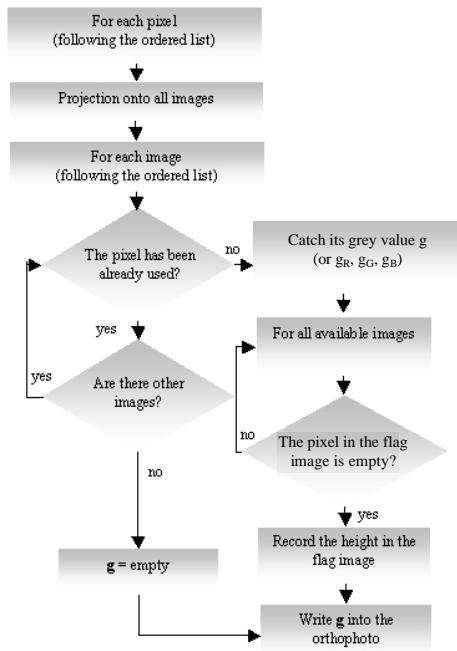


Figure 8: Flow-chart of the basic ACCORTHO functions

The main changes are:

- the final orthophoto image is divided into small windows, to minimize the computer power that is needed in the case of large format orthophoto production. It should be considered that the colour orthophoto of a map in 1:2000 scale (standard format) with a pixel size of 20 cm (~300 dpi) is composed of about 24 Mbytes (2300x3400 pixels).

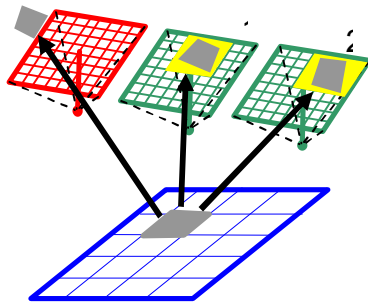


Figure 9: Window construction and image selection

- The ortoprojection procedure extracts the portion it considers useful for the orthophoto, from the available images, in each window (see fig. 9): in this way the loading operations of the starting digital images are limited, considering that, in the best case, there will be a maximum of 6 images.
- The orthophoto box can be defined on the basis of standard map sizes, the user just has to choose the reference scale and the sheet, and the software calculates the boundaries of the orthophoto that are necessary during the orthoprojection phase (circumscribed rectangle). White colour (255, 255, 255) is assigned outside the cartographic size in the final orthophoto.
- The software generates a georeferenced digital image, that is ready to use in a GIS.

The user interface has been completely re-developed, using the possibilities offered by Visual Fortran language in Windows OS. The main window (a), two loading data windows (b and c),

the window used to define the cartographic size (d), and the elaboration window (e) are shown in fig. 10. Italian and English versions are available.

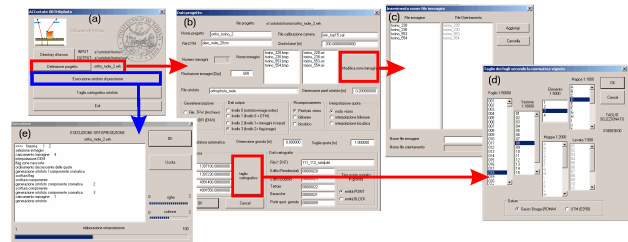


Figure 10: Dialogue windows of the ACCORTHO software

6. TRUE ORTHOPHOTO OF THE CITY OF TURIN

The Turin municipality decided to develop a local GIS, in collaboration with the Politecnico di Torino, to have an orthophoto coverage of the whole urban area (12.000 ha). This allowed the authors to test the implemented software. The map division of the area is shown in fig. 11, in 1:2000 maps. The highlighted part involves the historical centre of the city, which contains several architectural and historical buildings of great value.

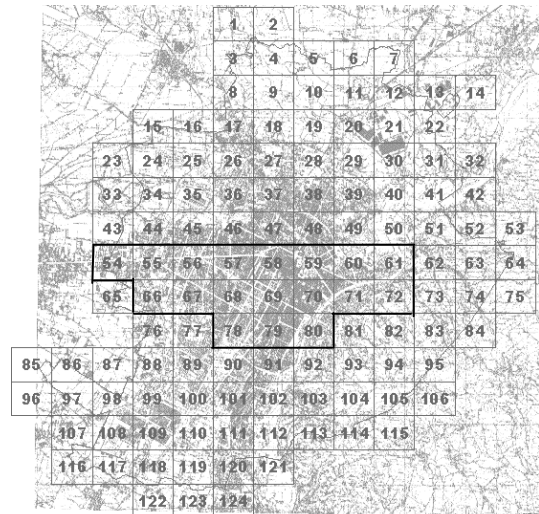


Figure 11: Maps involved in a first orthophoto production phase

6.1 Primary data

The initial data consists of:

- aerial photos taken on a recent acquisition flight (2002), acquired with a scanner at 600 dpi resolution, in JPEG format, oriented by aerial triangulation;
- a digital map at a scale 1:1000 containing all the data necessary to produce a DDTM, in DXF format.

The great automation of the software means that the initial data have to be arranged in a rigorous way.

Each aerial image requires a file that contains the internal and external orientation parameters. A specific software was developed for the external parameters to extract the coordinates of the projection centre and the angular parameters for each photo through an aerial triangulation procedure. All these parameters are recorded in a file which has the same name as the image and a .ori extension.

The digital map is reconstructed in a single file from which the

necessary sections have to be extracted, and an additional side strip of 300 m is added to avoid border effects.

The buildings of particular monumental and architectural importance require additional refining editing and photogrammetric restitution procedures. In these cases, the building coverage is modelled with horizontal surfaces (geometrically identified with a contour polyline and height point), or plane surfaces oriented in the space. Some examples are shown in fig 12.

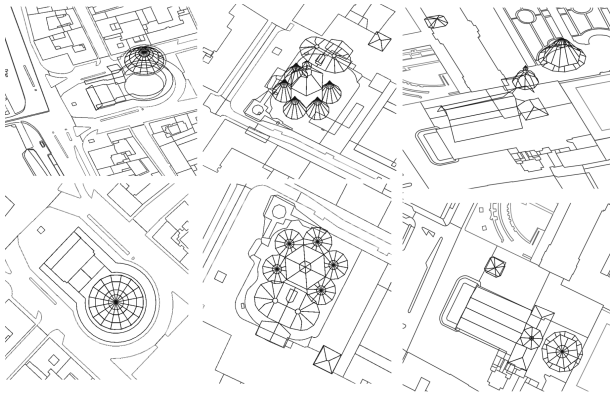


Figure 12: Examples of 3D representation of monumental buildings

6.2 DDTM Generation

A file containing data on the processing (such as the 300 m border strip, the chosen DDTM with pixel size of 20x20 cm², the codes of the entities involved and the interpolation type, bilinear) was compiled for each map.

The DDTMs were also produced as georeferenced digital images. In this way, their correctness could be tested by overlaying them on the digital map.

A digital grey-scale image (darker greys mean lower heights) of a DDTM in figure 13 is shown for an entire map (almost 7300x6300 pixels, corresponding to almost 45 Mb of memory allocation), generated by a standard PC (Pentium 4, 2 Ghz, 1 Gb RAM), in about one hour.

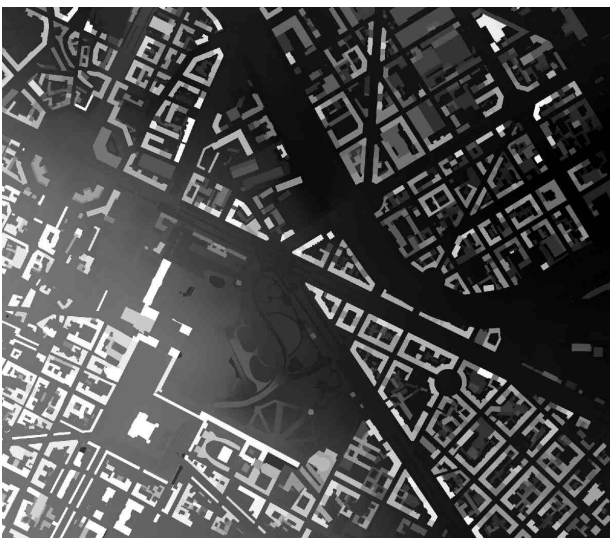


Figure 13: DDTM of the entire cartographic map

6.3 True orthophoto generation

A file for each map contains data on the size and position of the map, the name of the corresponding DDTM file,

interpolation type (nearest neighbour), and the orthophoto resolution on the ground (i.e. for example 20 cm).

The generated orthophotos were checked by overlaying them on a digital map, to find possible imperfections. To correct some residual errors, and to improve chromatic equalization, a post editing phase was made using Adobe Photoshop.

An entire orthophoto map (near 6600x5500 pixels, that means 208 Mb in True Colour mode) is shown in figure 14a that was generated in almost 2 hours with a standard PC (pentium 4, 2 Ghz, 1 Gb RAM), with a detail (figure 14b) overlaid with cartography (14c).

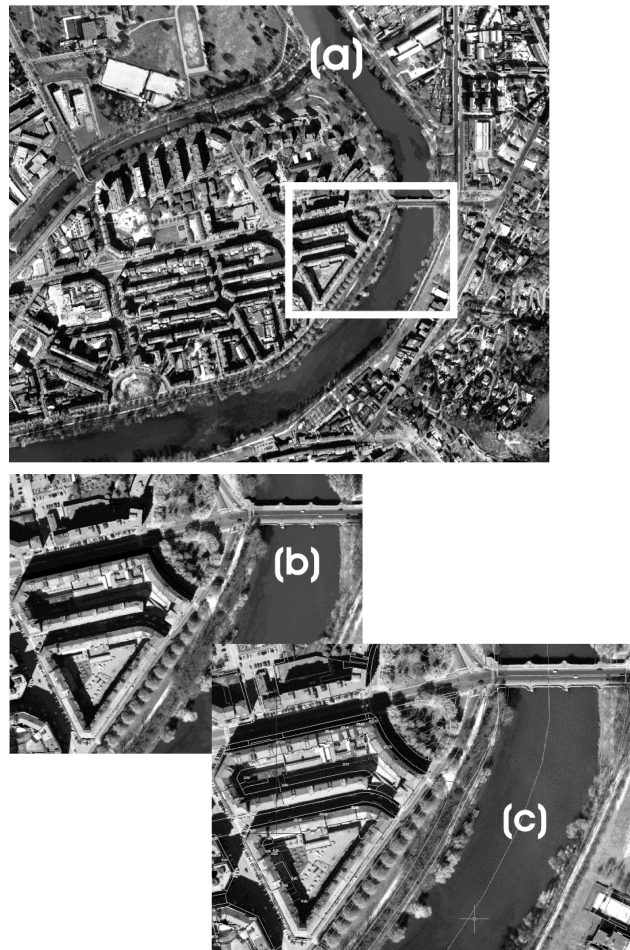


Figure 14: example of an orthophoto: an entire map (a), a portion (b), the same portion overlaid with cartography (c).

Some other important examples of monumental buildings extracted from the historical centre of Turin are shown in figure 15.

The image files that were obtained were saved in JPEG format, with a relative georeferencing file (Jgw): in this way they can be inserted with an automatic georeferentiation into any GIS software, as displayed in fig. 16.

7. ORTHO SOLID IMAGE

The image of a digital true orthophoto and the height values derived from DDTM can be merged in a new product: the *ortho solid image*, a simple extension of the 3D solid image (Bornaz, Dequal, 2003). In this case, for each pixel of an ortho solid image, it is possible to record:

- 3 colour values for the true colour image (RGB) extracted from the orthophoto and memorized in 3

bytes;

- 1 height value derived from the DDTM and memorized as an integer (2 or 4 bytes).

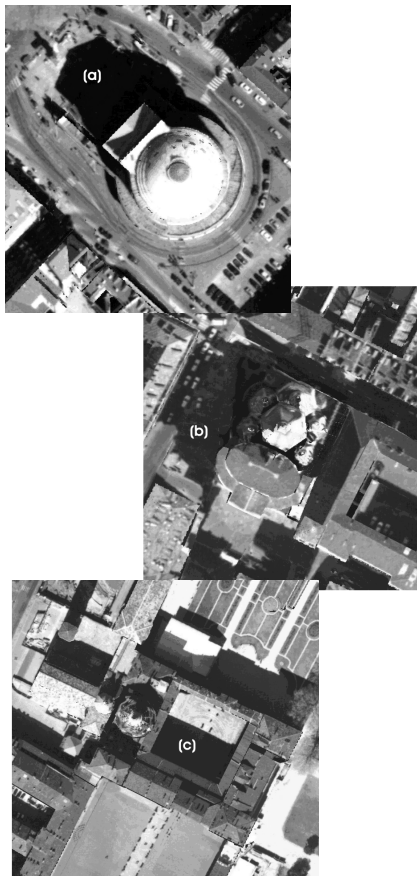


Figure 15: Orthophoto results of monumental building



Fig. 16: A GIS visualization of orthophoto images

If the height is expressed in cm, 2 bytes can represent a value that is between -327.67 m and +327.68 m. The memory required to store a ortho solid image is only 66 % greater than a simple orthophoto. If the considered heights are greater than these limits, 4 bytes that are able to represent any possible value in floating point format (up to 9999.99 m) can be used.

This new project permits to extract 3D information from the described objects in an easy and cheap way. In fact, an “ad hoc” software, that allows simple functions to query an ortho solid image, has been developed in Visual Fortran (with GINO 6.0 graphic libraries): this package provides zoom and pan functions, a 3D coordinate viewer and some measurement tools that are easy to use even by unskilled operators. The Windows

interface of this software is shown in figure 17.



Figure 17: An example of an Ortho Solid Image

8. 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 a DDTM through the use of already existing 3D digital cartography leads to a reduction of the production costs of the orthophoto, making it necessary to reconstitute only some monumental and new buildings. The ACCORTHO software, integrated with the GENEDDTM 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. The Ortho Solid Image is a new user-friendly tool that merges the image information contained in true orthophotos with the height information of DDTMs, to give a complete 3D description of the represented object.

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