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THREE DIMENSIONAL VISUALIZATION OF THE BUILT ENVIRONMENT USING DIGITAL ORTHOPHOTOGRAPHY

By A. GEORGOPOULOS, B. NAKOS, D. MASTORIS and D. SKARLATOS
National Technical University of Athens

Abstract

In this paper, different ways of performing large scale mapping of built up areas are discussed. Emphasis is placed on large scale representation through digital orthophotographs as the visualization medium of the real world. In an application, the process of creating perspective views of an orthophotograph draped on the digital terrain model of the study area is described; these views include the blocks of the built environment as three dimensional objects. The cartographic product is derived from a pair of overlapping aerial photographs processed through photogrammetric and GIS software packages. Finally, the perspective view of the digital orthophotograph is assessed as a large scale visualization tool for the communication of spatial information.

INTRODUCTION

GEOGRAPHIC VISUALIZATION is a powerful tool for representing space-related information in more perceptual ways, exploiting the continuously evolving computer technology. With this tool, computer graphics and rigorous numerical analysis have merged to produce reliable representations of geographic space within the framework of a geographic information system (GIS). This revolution in data representation involves a philosophical change that affords perception a more equal footing with mathematics and formal logic in scientific analysis (MacEachren and Monmonier, 1992; MacEachren, 1994). In this context, visualization means using visual tools, usually computer graphics, to help scientists explore data and develop insights about the infinite pieces of geographic information which modern technology is able to collect and store on magnetic media. In this sense, human vision, which was considered a potential source of bias, has now come to be recognized as a powerful tool for extracting patterns from chaos.

Large scale mapping of the built environment includes significant cartographic aspects which are particularly affected by the need to represent three dimensional objects, such as buildings and other man made constructions (Barnsley *et al.*, 1993). Generally, the terrain is conceived as a three dimensional continuous and smooth surface; this character must be retained in the different methods of representation. On the other hand, in large scale mapping, buildings and other three dimensional (3D) objects, placed on the surface of the earth and having significant relative size, produce non-continuous and non-smooth surfaces. It is very difficult to find ways of presenting, simultaneously, continuous and smooth surfaces with non-continuous and non-smooth surfaces. In this paper, work towards accomplishing a visualization tool to meet that requirement is described and the results are presented and discussed.

APPLICATION DESCRIPTION

In GIS tasks, visualization is composed of computational, cognitive and graphical design aspects in order to facilitate communication between the user and spatial

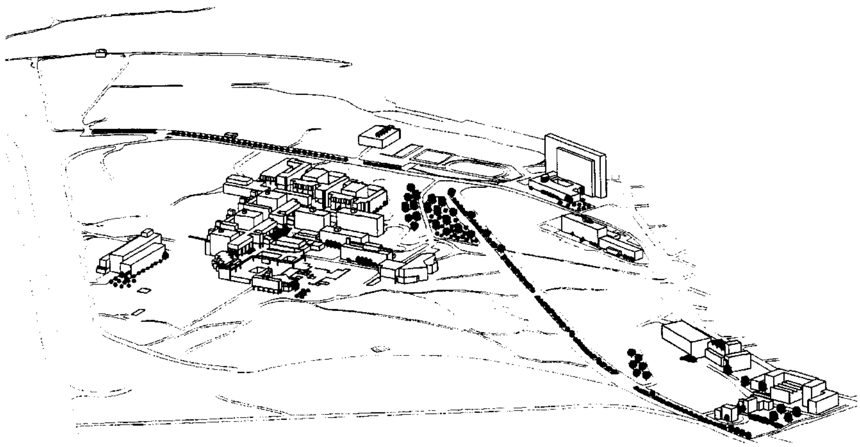

FIG. 1. Wire frame 3D visualization.

information (Kennie and McLaren, 1988; Buttenfield and Mackaness, 1991; Peterson, 1994; Rennison and Strausfeld, 1995). Traditionally, two dimensional representations of the data are the result. In these representations, the third dimension is usually symbolized with the help of sections which are either horizontal, in which case the well known contour lines are produced, or vertical. The most typical 3D surface visualizations are generated from perspective views of contour plots (McCullagh, 1988), requiring a digital elevation model (DEM) of the study area and appropriate software for the analytical calculations. The perspective views of contour plots, as visualization tools, have limited communicative results, giving poor graphical outputs. Representations of the surface of the earth with contour lines are interpreted with difficulty by users without engineering knowledge. Shaded graphical representations mimicking natural phenomena can produce more effective visualization tools (Imhof, 1982). A more realistic approach would be a combination of the perspective view of the terrain, as described above, with wire frame models of constructions. Such a combination has been attempted by Mavromati (1994) and Georgopoulos *et al.* (1995) and is presented in Fig. 1.

In order to overcome the deficiencies mentioned above and produce a more realistic large scale 3D representation of the geographic environment, digital photogrammetric techniques have been employed. For this purpose, a stereoscopic pair of overlapping aerial photographs was used to produce the necessary three dimensional information of the terrain surface (DEM) and the buildings. The photographs were at a scale of 1 : 6000, on black and white negative film. The overlapping stereopair was processed on an Intergraph ImageStation digital photogrammetric workstation. The available paper prints were scanned on a Sharp JX-610 A3 scanner at a resolution of 600 dpi. The interior, relative and absolute orientations, using six control points evenly distributed over the area of interest, were performed satisfactorily using the corresponding modules of the workstation. The results are presented in Table I.

TABLE I. Accuracy of orientations.

Type of orientation		*Number of points*	*Residuals*
Interior	left photograph	4	$\sigma_0 = 0{\cdot}001$ mm
	right photograph	4	$\sigma_0 = 0{\cdot}001$ mm
Relative		26	$\sigma_0 = 16\ \mu$m
Absolute		6	$\sigma_X = 0{\cdot}6$ m, $\sigma_Y = 0{\cdot}8$ m, $\sigma_Z = 0{\cdot}1$ m

The residuals on the control points, after the orientation procedures, were of the order of 0·50 m, which was considered adequate for the desired 1:5000 orthophotograph. Subsequently the Match-T program, which is included in the software available from Intergraph, was used to produce the DEM automatically, with a grid point density of 3 m on the ground. This program employs digital least squares correlation, in order to extract homologous points and determine their elevations, taking into account the breaklines eventually determined by the user. The DEM produced in this way needed some editing, in order to refine the elevations of dubious points.

Finally, using the resampling routine of the ImageStation, the digital orthophotograph of the area of interest was produced. This is an important photogrammetric product, which combines the quantitative reliability of a conventional map and the rich qualitative information of an air photograph (Kraus, 1986). The combination of the DEM and the orthophotograph produced the 3D representation of the terrain and the man-made constructions in the area.

Visualization Design

The proposed visualization process is based on consecutive analytical transformations of raster aerial images, forming an overlapping stereopair, to a perspective view as would be naturally perceived by the human eye.

The 3D view (Fig. 2(i)) comprises three elements:

(i) perspective view of the digital elevation model (Fig. 2(g));
(ii) perspective view of the orthophotograph (Fig. 2(f)); and
(iii) representations of the elements of the built environment (Fig. 2(h)).

A digital elevation model (DEM) is a numeric representation of the terrain, in the form of a matrix based on a regular grid. It is a powerful tool for deriving contour lines, sections or even 3D views of the surface of the earth.

Orthophotography is the transformation of an image from central projection to orthogonal projection, maintaining all the qualitative information (such as colour variation, roads, borders and so on) of the original image. This implies that the orthophotograph is free from scale distortions, which are caused by relief and tilt variations in the central projection, thus forming a reliable metric document which is very similar to a conventional map.

The built environment can be represented by abstract geometrical 3D objects. This is considered necessary because existing DEM derivation algorithms are unable to model non-continuous and non-smooth surfaces.

The source material of the three components of the visualization process is the overlapping pair of images (Fig. 2(a and b)). This implies that the orthophotograph, the DEM and the 3D representations of the built environment can be derived simultaneously using photogrammetric methods. The most crucial product is undoubtedly the DEM, which may be produced with the help of specialized equipment such as photogrammetric stereoplotters. Digital technology has now influenced all photogrammetric operations and DEM production can be carried out fully automatically, saving considerable time and producing a more reliable result. The DEM derived in this way from the stereopair is able to exploit to the limits the density of information contained in the original images. However, it still needs some refinement, with the help of suitable breaklines, in order to take into account even the most detailed elements of the terrain surface.

The DEM, produced automatically, is used in combination with one of the two images of the stereopair to perform the necessary transformations and to generate the orthophotograph from the image (Fig. 2(c)). These transformations involve the transition from central to orthogonal projection and the elimination of all scale variations while, at the same time, the original colours are preserved. Current algorithms for the production of orthophotography are not able to take into consideration sharp elevation variations (non-continuous and non-smooth surfaces), as occur in the case of buildings and other artificial constructions. This problem has been solved by using the 3D representations of buildings, while the DEM is derived, by excluding their

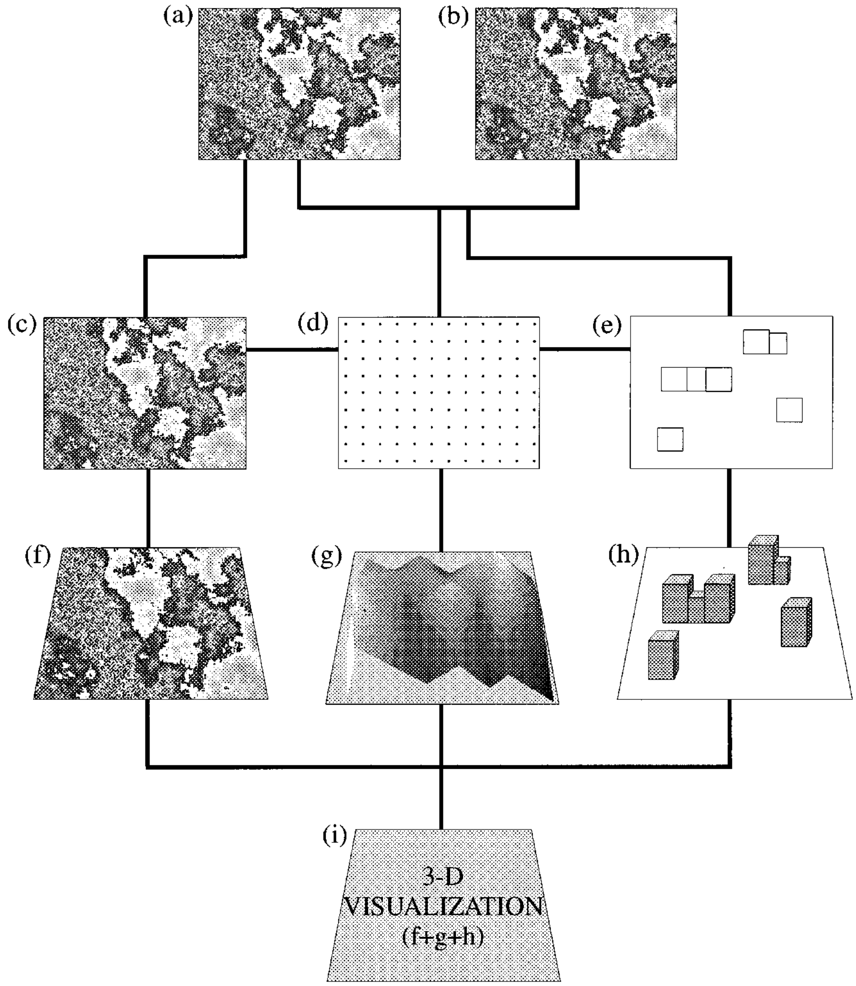

FIG. 2. The design procedure for the 3D visualization process.

positions from the interpolation. In this way building locations are omitted from the original DEM.

The information required in order to form 3D representations of buildings may also be produced from the stereopair using manual conventional photogrammetric techniques. These data are used to enrich the DEM with more detailed information, concerning the non-continuous surfaces of the buildings, through an interactive editing procedure. The procedure involves inserting suitable "elevations" at the DEM nodes covered by the buildings. According to the concept described, the representation of buildings as three dimensional objects is strictly related to the density of the final DEM (3 m to 5 m). In practice, due to the DEM interpolation process, the shape of a building in a vertical section has a trapezoidal form (Fig. 3), which is perceived as orthogonal by the human eye in large scale (for example 1:1000 or 1:5000) representations. The choice of representation scale is critical and it depends on (i) the DEM density; (ii) the absolute height of the buildings; (iii) the exaggeration factor for the third dimension; (iv) the final resolution of the digital output; and (v) the resolution of the human eye. The various faces of the buildings or other constructions are finally shaded, using a suitable artificial illumination model (Imhof, 1982; Horn, 1982; Tzelepis and Nakos, 1996).

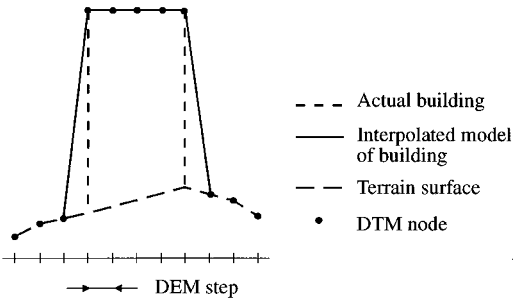

FIG. 3. DEM modification for buildings.

The three components of the visualization process are integrated graphically by transforming the digital image of the orthophotograph (Fig. 2(f)) and the modified DEM (Fig. 2(g and h)) to the same perspective view (Fig. 2(i)) using a draping procedure. The elevations are usually exaggerated by a specific factor in order to help the user interpret the terrain more reliably. This exaggeration factor, however, can cause visibility problems and its optimum value is determined interactively in relation to the location of the viewing point.

VISUALIZATION IMPLEMENTATION

In order to put all the above design considerations to a practical test, it was decided to produce an orthophotograph of a suitable area. The campus of the National Technical University in Athens was chosen. This area presents considerable variations in relief because it is located at the foot of a mountain and the buildings in certain areas are quite densely located. Moreover, work on a 3D wire frame visualization of the area had already been carried out (Mavromati, 1994; Georgopoulos *et al.*, 1995). Hence comparison and discussion of the resulting output would be possible.

The data required for the implementation of the project are the following (Mastoris and Skarlatos, 1995):

(1) a pair of overlapping aerial photographs at a suitable scale; and
(2) a small number of control points, with known three dimensional co-ordinates.

The stereopair of aerial photographs at a scale of 1:6000 was obtained from the Ministry of Environment and Public Works. This scale of photography is suitable for producing photogrammetric products at a maximum scale of 1:1000; it is capable of representing a comparatively large amount of detail in view of its high spatial resolution (0·25 m). As control points, trigonometric points spread around the campus were used, with co-ordinates in the Greek Geodetic Reference System (GGRS 87). For the purposes of this project, the elevations of all the buildings and other constructions were required; these were derived from the photogrammetric restitution which had been carried out for the wire frame 3D representation of the same area (Mavromati, 1994).

The data processing steps needed to produce the final output are shown in Fig. 4 and were implemented using an Intergraph digital photogrammetric workstation. Since the whole procedure involved digital techniques, the two photographs were digitized with the help of a flatbed scanner with a resolution of 600 dpi. This was considered adequate because this resolution would meet the accuracy demands of the final output scale.

After interior orientation, relative and absolute orientation were undertaken on the digitized stereopair. Using digital correlation techniques, a large number of homologous points were determined in the stereopair and their 3D co-ordinates were

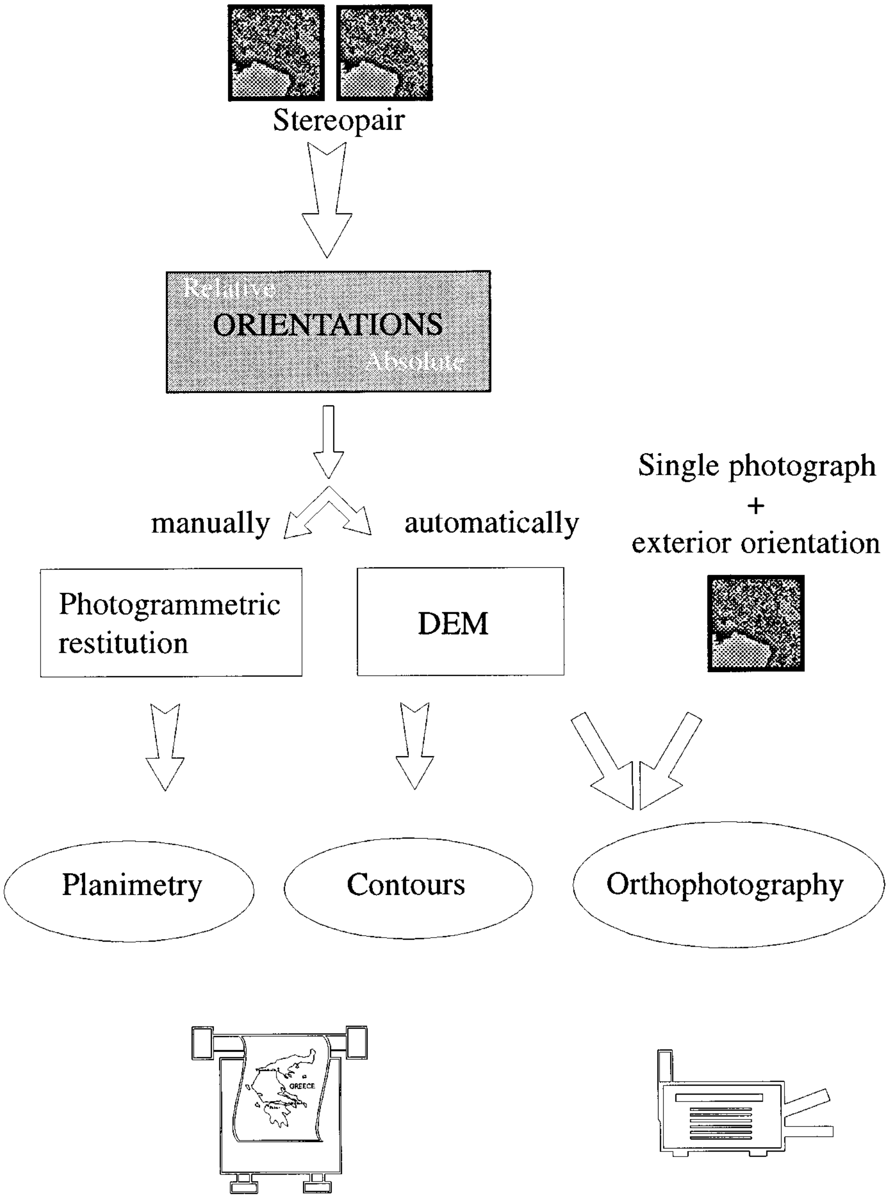

FIG. 4. The implementation procedure for the 3D visualization process.

calculated. Thus the DEM of the area was automatically defined. The final DEM was enriched through the insertion of suitable breaklines, in order to ensure that the terrain was described as comprehensively as possible. At the exact positions of the buildings, the DEM was cut and any interpolation was excluded. In this way the problem of elevation discontinuities was overcome manually. The final DEM therefore described the terrain with the exception of the building locations.

The next step was the production of the digital orthophotograph (Fig. 5). It is built on a pixel by pixel basis using the known orientation of the image and the DEM of the area imaged, in order to determine the correct position of each new pixel in the

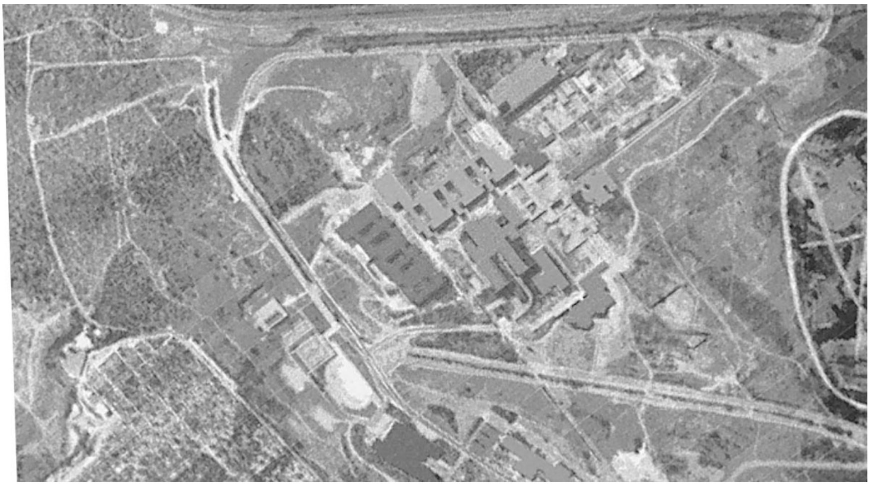

FIG. 5. Orthophotograph of the study area.

FIG. 6. 3D perspective view of the study area.

orthogonal projection and its colour or grey tone. An orthophotograph is considered to be very valuable, because it conveys a large amount of visual information combined with correct metric position. In the digital era of photogrammetry, the production of orthophotography has become more automated and cost effective and it is expected that in the future it will be more widely used.

The final step was the production of the 3D view as a perspective image, consisting of the orthophotograph draped on the modified DEM (Fig. 6). The elevation exaggeration factor was selected to be 2:1 and the viewing point was chosen to be close to the one defined for the image of Fig. 1. The density of the DEM was selected to have a step of 0·65 m, which allows users to magnify the image up to a scale of 1:2000, while the building edges appear practically vertical.

Discussion and Conclusions

A first comparison between Figs. 1 and 6 shows clearly how the perspective view of the visualization process proposed is more realistic and better perceived than the wire frame version. The image of Fig. 6 is more close to what the human eye would see from the same location. In addition, since all the parameters of the perspective view are known exactly, analytical tools can easily be developed in order to enrich the qualitative features with quantitative information. The user can measure distances and angles, calculate areas of closed polygons and determine volumes of different objects.

Furthermore, the final digital product can be enhanced with the addition of the details of the building façades. This can be achieved either manually, by inserting perspectively distorted images of the façades, or automatically by calculating the required tilts of the corresponding digital photographs. It is possible to add new features to the perspective view, or to modify existing elements (such as buildings or other constructions), in accordance with relevant regional planning proposals. This procedure is known as *inverse photogrammetry* and is very useful in determining the impact of planned modifications before they are actually built.

Finally, depending on the availability of powerful hardware and software, consecutive perspective images along a predefined path may be created, so that the user can perceive a realistic 3D "fly-over" or "walk-through" of the area of interest.

In conclusion, it has been shown that modern photogrammetric methods and related products are powerful tools for aiding the visualization process. As technology advances rapidly and the various digital products become increasingly accessible, they should be seriously considered for acceptance in everyday practice.

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Résumé

On examine dans cet article différentes façons de réaliser une cartographie à grande échelle de zones construites. On met l'accent sur l'emploi d'orthophotographies numériques comme moyen de visualisation du monde réel et de représentation à grande échelle. On décrit en application le processus de production de vues perspectives composées du modèle numérique de terrain de la zone étudiée, habillé de l'orthophotographie; ces vues contiennent les silhouettes des bâtiments qui constituent des objets tridimensionnels. On obtient le document cartographique à partir d'un couple de photographies aériennes en recouvrement traité par un ensemble de logiciels photogrammétriques et de SIG. On considère finalement que l'orthophotographie numérique est un moyen de visualisation à grande échelle, en vue perspective, permettant de communiquer l'information dans l'espace.

Zusammenfassung

In dem Beitrag werden verschiedene Wege zur Herstellung großmaßstäbiger Karten bebauter Gebiete diskutiert. Betont wird dabei die großmaßstäbige Darstellung mit Hilfe digitaler Orthophotos als Mittel der Visualisierung der realen Welt. Als Anwendung wird der Prozeß der Herstellung perspektiver Ansichten aus einem Orthophoto, das einem digitalen Geländemodell des Versuchsgebiets überlagert wird, beschrieben. Diese Ansichten schließen die Blöcke der bebauten Umwelt als dreidimensionale Objekte mit ein. Das kartographische Erzeugnis wird aus einem Paar sich überlappender Luftbilder abgeleitet, die mit Hilfe von Softwarepaketen zur Photogrammetrie und für GIS verarbeitet wurden. Schließlich wird die perspektive Ansicht des digitalen Orthophotos als großmaßtäbiges Visualisierungswerkzeug zur Kommunikation mit Rauminformationen bewertet.