AN INTEGRATED SOLUTION FOR THE PROBLEMS OF 3D MAN-MADE OBJECTS IN DIGITAL ORTHOPHOTOS

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ABSTRACT:

Especially for geographic information systems (GIS) of urban areas large scale digital orthophotos are increasingly important. Inadequate description of 3D man-made objects and conventional orthophoto algorithms cause geometric errors visible in form of displacement and double mapping. A solution for precise mapping based on image separation and independent rectification of terrain and building areas will be presented. An integrated solution should handle all related tasks that are object acquisition, modelling and orthophoto generation.

KURZFASSUNG:

In städtischen Gebieten sind großmaßstäbliche digitale Orthophotos für geographische Informationssysteme von großer Bedeutung. Aufgrund des üblicherweise angewandten Algorithmus zur Orthophotoherstellung, sowie der unzureichenden Modellierung von Kunstbauten ergeben sich Fehler in Form von geometrischen Versetzungen und Doppelabbildungen. In diesem Bericht wird eine Methode zur Herstellung von geometrisch exakten Orthophotos vorgestellt. Sie basiert auf einer unabhängigen Entzerrung von Kunstbauten und Gelände mittels vorangegangener Bildseparation. Anschließend werden Vorschläge für ein umfassendes System zur Herstellung digitaler Orthophotos diskutiert.

1. INTRODUCTION

Digital orthophotos in combination with GIS are a usefull instrument for monitoring changes in rapidly growing cities. It is expected that in the 21st century, more than 70% of earth citizens will live in cities. Therefore accurate mapping of cities in digital orthophotos is very important.

Today's systems for digital orthophoto generation do not model 3D man-made objects such as buildings, bridges or multilevel highways (in this paper, „building" and „3D man-made object" will be used as synonym). Therefore large scale (i.e. 1:5000 - 1:10000) orthophotos of urban areas show disturbing geometric errors in form of displacement and double mapping.

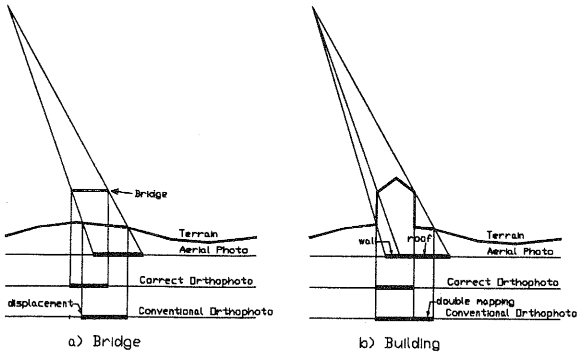
Erroneous pixels in common digital orthophotos amount to about 8% and more - depending mainly on building density and height (Amhar, Ecker, 1995). This causes serious problems for further applications such as data overlay, 2D coordinate measurement or 3D visualization.

This paper presents a method for accurate mapping of 3D man-made objects in digital orthophotos. It is based on image separation and independent rectification of terrain and building areas.

1.1 Mapping Problems

Today's orthophoto systems use only Digital Terrain Models (DTM), but do not care about buildings. Displacement and double mapping as can be seen from figure-1 are the results of inadequate description of the shape of 3D man-made objects and the algorithms applied.

Figure 1a shows the terrain surface modelled by the DTM and a bridge. Since the shape of the bridge is not modelled at all, the bridge will be displaced as can be seen in layer „conventional orthophoto". The proper position is marked in layer „correct orthophoto". In Figure 1b the building is included in the DTM. This approach results in a correct position of the roof pixels in the orthophoto, but has the disadvantage of double mapping in hidden surface areas.



a) Bridge b) Building

Fig.1: Displacement and double mapping

Therefore city orthophotos require measurement of all 3D man made objects stored in a digital building model (DBM).

1.2 Related Works

Geometric aspects of 3D-objects are intensively discussed in (Turner, 1992). Experiments with an object oriented model are presented by (Heytens, Sacchi, 1993). (Li, 1994) gives an overview of several common 3D-data structures. (Lang et al, 1995; Haala 1995) deals with problems of automated building extraction from aerial images. An approach to mapping of buildings is given in (Gruen et al, 1994). A technique of orthophoto generation using a DTM with breaklines is discussed in (Ecker, 1991). Visualisation techniques of buildings models are presented in (Kuhn, 1990) and rigorous 3D modelling of city landscape is done by (Gruber et al , 1995; Ranzinger, Gleixner, 1995; Sinning, Gruen, 1995).

2. PROPOSED SOLUTION

The proposed solution for accurately mapped orthophotos requires the following processes:

- digital building model generation
- building orthophoto computation
- terrain orthophoto computation
- raster algebra

The digital building model determines the shape of each building and is required for the subsequent process of building orthophoto generation.

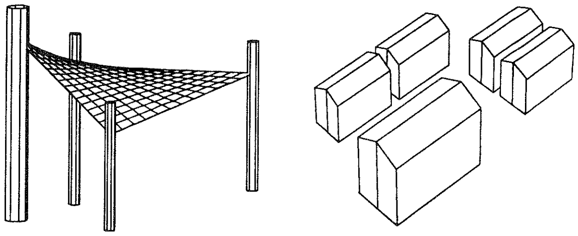
Since conventional orthophotos systems can hardly model building surfaces and do not care about hidden surfaces, an algorithm has been developed for this purpose. It will be presented in detail in chapter 2.2. The result of this process is an orthophoto of all buildings and a building mask indicating buildings in the aerial image.

For the subsequent generation of the terrain orthophoto it is sufficient to apply the conventional orthophoto method. But the input is not the original aerial image but an aerial image with grey value 0 in building areas. This modified aerial image can be generated using the building mask.

By using raster algebra as described in chapter 2.4 it is possible to combine terrain and building orthophoto.

2.1 Digital Building Model (DBM)

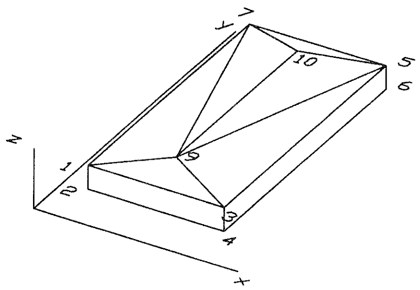
There are many types of 3D-objects visible in aerial images. Natural objects such as trees will not be considered in this work. An overview of man made objects (buildings) and their representations is given in figure 2. Similar homogeneous objects can be stored economically using implied topology. Complex objects might be approximated by mathematical functions and construction rules.



a) b)

Fig.2: a) Complex object
b) Mass parametrical objects

For large scale orthophotos objects of figure 2b are important. A flexible solution to model this types of objects is boundary representation (B-Rep). This technique uses geometric primitives to describe objects boundaries. It is sufficient to choose triangles and quadrangles as geometric primitives. Beside from geometric shape the building model manages also attribute information for each geometric primitive. The digital building model distinguishes between primitives that are visible in the orthophoto (e.g. roof) and invisible (e.g. wall, vertical roof). Figure 3 shows a building and its representation in the digital building model.



Coordinates	Wall	Roof
$x_1\ y_1\ z_1$, $x_2\ y_2\ z_2$,	*1 3 4 2,*	*1 3 9,*
$x_3\ y_3\ z_3$, $x_4\ y_4\ z_4$,	*3 5 6 4,*	*3 9 10 5,*
$x_5\ y_5\ z_5$, $x_6\ y_6\ z_6$,	*5 7 8 6,*	*5 10 7,*
$x_7\ y_7\ z_7$, $x_8\ y_8\ z_8$,	*7 1 2 8*	*7 10 9 1*
$x_9\ y_9\ z_9$, $x_{10}\ y_{10}\ z_{10}$		

Fig.3: Representation of a building
in the digital building model

For citywide orthophoto generation with thousands of buildings a database system is necessary to manage all these data. At the Institute for Photogrammetry and Remote Sensing TOPDB has been developed (Loitsch, Molnar, 1991). It is a relational database system extended with topological data types and operators. The communication is done by an SQL subset called TOPSQL. TOPDB is well suited for the management of a building model and will be used for this purpose.

2.2 Building Orthophoto Generation

In contrast to conventional orthophoto techniques, this algorithm must consider hidden surface areas. Z-Buffer algorithms are a well known solution for this problem but require much memory. Therefore another solution will be proposed.

With this algorithm all objects (buildings) of the area of interest in the DBM will be processed sequentially. The simple data structure of the building model enables fast segmentation of an object into triangles. Figure 4 shows the triangle F defined by F_1, F_2 and F_3 representing a part of a house. The corresponding triangle F' in the image coordinate system can easily be computed. The area of F' will be rastered and stored in the building mask and in a local bitmap with reference to the image coordinate system. Pixels covered by F' will be filled with grey value 0 in the building mask and bitmap. The building mask will be required for the generation of the terrain orthophoto, whereas the small bitmap is necessary to determine visible pixels of F'.

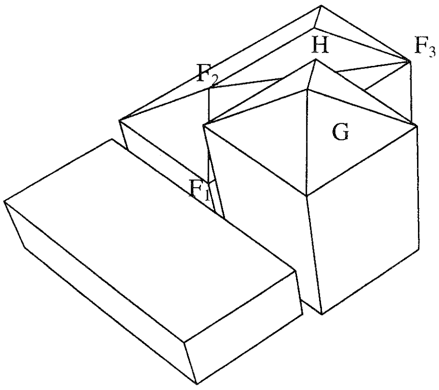


Fig. 4: Simple building model

Next all objects intersecting with pyramid F_1, F_2, F_3 P (projection center) have to be identified. Triangle G in Figure 4 is a face of one of these objects. If there is an intersection of G' (image of G) with F', G' will also be rastered and the corresponding bitmap pixel will be set to 1. Thus only visible pixels of F' have grey value 0. The algorithm continues within a loop for all other graphic primitives and objects and stops if all intersecting objects are processed or all pixels of F' are set invisible. In the first case the rectification of the visible parts of F' will be performed. Of course rectification will only be done for roofs and not for walls. Suitable resampling functions are found in (Kraus et al, 1996). Now the algorithm continues processing the next face (in figure 4 it is H) until all objects are rectified.

2.3 Terrain Orthophoto Generation

Terrain orthophoto computation requires building mask, aerial image and DTM. Building mask and aerial image are merged into a modified aerial image with blank pixel (grey value 0) in building areas. Therefore the original grey values of this photo must be scaled to the range [1,255]. The modified aerial image will be used for the computation of an orthophoto without buildings. For this process any conventional orthophoto software can be applied. The combination of the resulting terrain orthophoto and building orthophoto can be done by raster algebra and will be discussed in the next chapter.

For an improved solution it is not necessary to modify the aerial image. The orthophoto software uses aerial image and building mask simultaneously. Moreover it is also possible to use the building orthophoto as input. The rectified terrain surface will be automatically added to the building orthophoto.

2.4 Raster Algebra

For the final orthophoto generated from one aerial image the terrain orthophoto and the building orthophoto have to be combined by raster algebra. Figure 5 shows input grey values and resulting grey values of the orthophoto.

		Building orthophoto	
		0	g_B
Terrain orthophoto	**0**	0	g_B
	g_T	g_T	g_B

Fig. 5: Combining terrain and building orthophoto by raster algebra

Grey value 0 represents buildings or hidden surface areas in the terrain orthophoto. In the building orthophoto pixels with grey value 0 identify areas imaging terrain surface. $\mathbf{g}_B$ and $\mathbf{g}_T$ represent rectified surfaces in the corresponding orthophoto.

Of course orthophotos generated from one image only might contain patches without image contents (hidden areas) represented by grey value 0 in figure 5. A final orthophoto with no blank area can be obtained by merging overlapping orthophotos derived from different images by raster algebra. Figure 6 shows the required raster algebra.

		Orthophoto no. 2	
		0	g_2
Orthophoto no. 1	**0**	0	g_2
	g_1	g_1	$g_{1,2}$

Fig. 6: Mosaicking two overlapping orthophotos by raster algebra

For pixels mapped in both orthophotos an appropriate rule (e.g. average) has to be applied to compute the final grey value $\mathbf{g}_{1,2}$.

3. ORTHOPHOTO PRODUCTION ENVIRONMENT

3.1 Data Acquisition

Currently data capturing for building models is usually done manually on analytical or digital photogrammetric stereo digitizers. Approaches for automated data acquisition applying digital techniques are still under development (Lang, 1995; Haala 1995). Therefore simple procedures for manual acquisition on a stereoplotter integrated into a CAD environment are of great importance. Capturing of DTM-data and 3D man-made object data will be done simultaneously.

The usage of existing data generally captured for other purposes (e.g. maps etc) is very difficult. In most cases these data are stored in two dimensional GIS. Therefore additional information such as 3D topology, elevation, etc. is required. Inconsistency of these data sets is another big problem. It is caused by data acquisition using different methodes, at different epochs for different purposes.

Since data acquisition for building models is very time consuming, municipalities of big cities should set up data sets for multipurpose future usage.

3.2 Modelling

Fortunately many buildings (especially in suburban areas) are of simple shapes. In this case it is sufficient to digitise roofs only. Walls can be computed from roofs (eaves) and DTM (see figure 7) on the assumption that eaves and terrain are boundaries et walls. This methode is not to apply for overhangs.

Three dimensional triangulation algorithms with geometric constraints (Halmer et al, 1996) are necessary for automatic generation of geometric primitives as described in chapter 2.2 (see figure 8). This method is used to model details within roofs. A test detects nearly vertical roofs to be classified as wall.

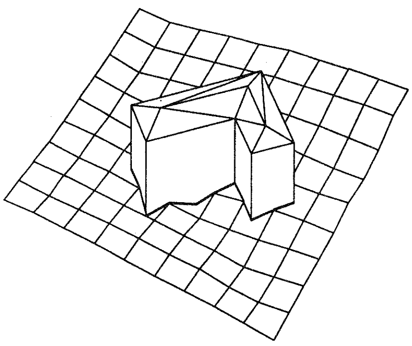
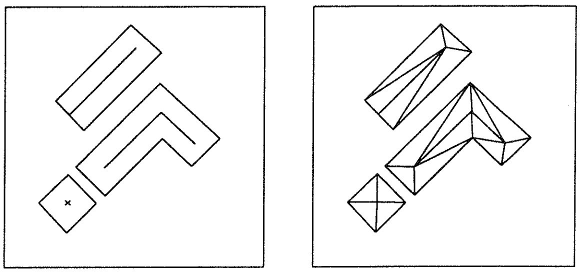


Fig 7: House modelling by roof and terrain data



a) input b) result

Fig. 8: Triangulation with geometric constraints

For complex bodies, modelling must be done simultaneously with capturing. Therefore the integration of modelling and capturing modules is necessary.

In some countries buildings are very similar and therefore it is possible to prepare standard buildings with same topology (Ranzinger, Gleixner, 1995). (Lang et al, 1995) proposes a method for semi automatic topology building. Digital photogrammetric methods such as edges extracting or matching might be extended to 3D-topology matching.

3.3 Orthophoto Management System

For citywide orthophoto generation (with several hundred thousand buildings and also several thousand digital photos and associated control data), a database system is necessary to manage all these data.

This orthophoto management system should handle all relevant data:

- aerial images including image properties (orientation, etc).
- digital terrain model
- digital building model

Required data for orthophoto computation will be made available by the system. Another important task is data exchange (import, export) with other systems.

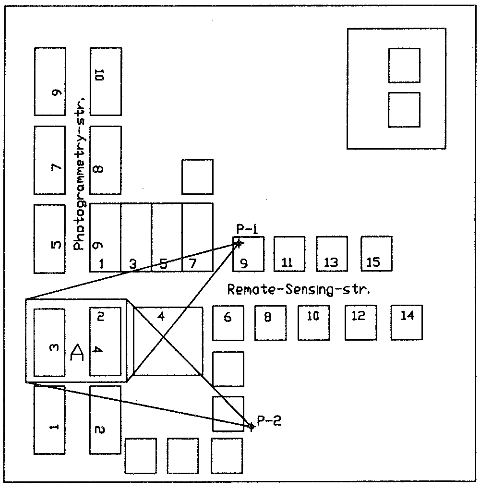


Fig.9: Object partitioning

For very large data sets of building models partitioning is necessary. Figure 9 shows a small area of interest (A) for orthophoto computation. Buildings located in the sector defined by projection center P-1 and area A are required for this purpose. TOPDB could be used for this task. A database with full ability for 3D queries would meet all requirements of partitioning.

In order to fill hidden areas in (A), overlapping aerial images are necessary. P-2 ist the projection center of this overlapping image. In this case also buildings located in sector P-2, A are required.

4. EXAMPLE

The proposed method has been checked with data from Vienna. Figure 10 shows a conventional orthophoto of the test area.

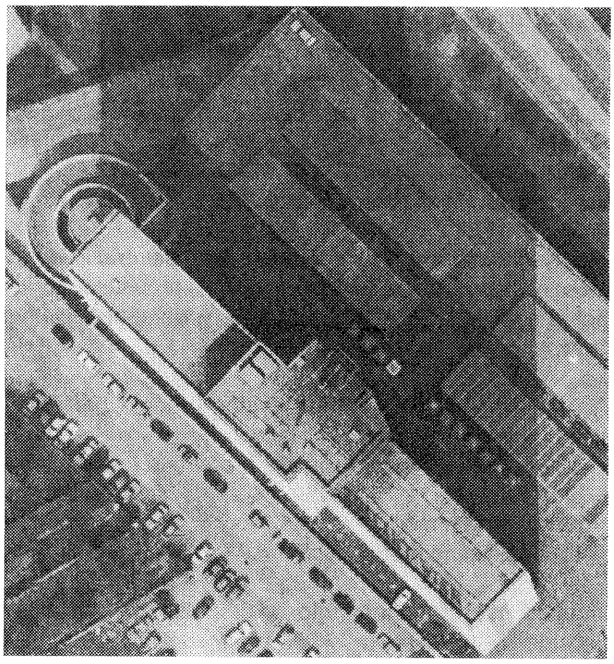


Fig. 10: Conventional orthophoto

A program has been developed to extract data of the multipurpose city map. Extracted terrain data were used to compute a digital terrain model with the DTM-software SCOP. The digital building model was generated in TOPDB. In some cases of inconsistency remeasurements of building data were necessary. Triangulation of roof elements has been done manually, since this algorithm is still in work.

Based on the digital building model the building orthophoto could be computed. The generated building mask was used for the computation of the terrain orthophoto. Figure 11 shows the combination of terrain and building orthophoto. The black area around the building indicates hidden surfaces. Figure 12 is a mosaic of two orthophotos. Therefore hidden surface areas could be minimized. The geometric distortion of the ramp are the result of an incomplete building model.

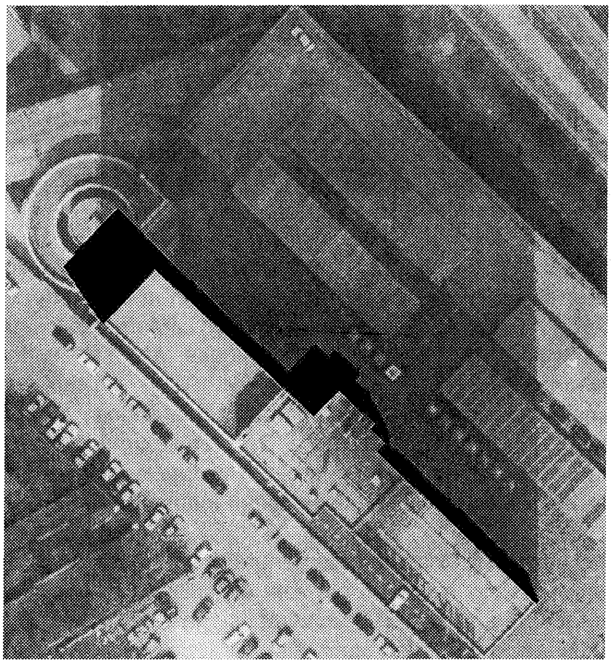


Fig.11: Orthophoto with accurately mapped building

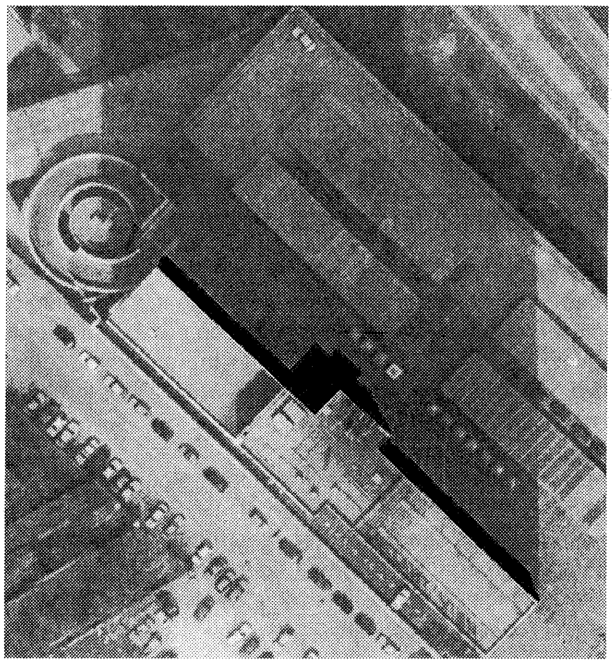


Fig. 12: Orthophoto mosaic

5. CONCLUSION

The generation of large scale digital orthophotos in urban areas requires an integrated solution for data acquisition, modelling and rectification. Rectification is based on four steps that are: generating of building mask, generating building orthophoto, generating terrain orthophoto. The last step is the combination of both orthophotos. It is also possible to image hidden surface areas by mosaicking orthophotos compiled from different aerial images.

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