THE GENERATION OF TRUE ORTHOPHOTOS USING A 3D BUILDING MODEL IN CONJUNCTION WITH A CONVENTIONAL DTM

Fahmi Amhar
Mapping Centre Bakosurtanal, Indonesia
email: blombog@indo.id
Josef Jansa, Christine Ries
Vienna University of Technology, Austria
email: Josef.Jansa@tuwien.ac.at and chr@ipf.tuwien.ac.at

KEYWORDS: True Orthophoto, Building Model, Visibility Analysis

ABSTRACT

For the time being usual orthophotos do not place general 3D objects (buildings, bridges, etc) on their geometrically correct positions because conventional algorithms are based on 2.5D digital terrain models (DTM) thus limiting significantly the possibility of describing the real 3D shape of the objects and inhibiting the correct calculation of visibility. For large and medium scale image maps quite often the effect of wrong mapping cannot be tolerated any more and the generation of so-called true orthophotos becomes obligatory. In addition to the DTM 3D digital building models (DBM) must be introduced. Here three approaches are presented dependent on the complexity of the object surface. The methods differ in the way to treat the DTM and DBM in the rectification process and in the visibility analysis. Open areas with simple buildings do not need visibility analysis at all, while in urban areas with complex buildings visibility analysis within the DBM becomes compulsory. The most general approach performs a visibility analysis within the DSM (digital surface model) which is a common data base of DBM and DTM. A true orthophoto program has been developed, that can create all three types of orthophotos from aerial as well as close-range photographs.

KURZFASSUNG:

Bisher sind in digitalen Orthophotos allgemeine 3D-Objekte (Gebäude, Brücken, etc.) geometrisch falsch abgebildet, weil konventionelle Orthophotoalgorithmen auf 2.5D-Geländemodellen (DTM: *Digital Terrain Model*) basieren, mit denen 3D-Objekte nur unzureichend beschrieben und keine Sichtbarkeiten berücksichtigt werden können. In großen bis mittleren Maßstäben sind diese Fehler häufig nicht mehr tolerierbar und es besteht ein großer Bedarf an sogenannten *True*-Orthophotos. Grundvoraussetzung für die Generierung eines *True*-Orthophotos ist ein 3D-Gebäudemodell (DBM: *Digital Building Model*). Hier werden drei Möglichkeiten für die Erzeugung eines *True*-Orthophotos vorgestellt, die in Abhängigkeit von der Komplexität der Objektoberfläche angewandt werden. Die Methoden unterscheiden sich in der Art, wie das DTM und das DBM im Rektifizierungsprozeß und in der Sichtbarkeitsanalyse behandelt werden. Offene Gebiete mit einfachen Gebäuden brauchen keine Sichtbarkeitsanalyse, während in städtischen Gegenden mit komplexen Gebäuden eine Sichtbarkeitsanalyse innerhalb des DBMs unumgänglich wird. Im allgemeinsten Fall wird die Sichtbarkeitsanalyse für das digitale Oberflächenmodell durchgeführt (DSM: *Digital Surface Model*), das als gemeinsamer Datensatz aus DBM und DTM zu verstehen ist. Ein *True*-Orthophotoprogramm wurde entwickelt, das die Erstellung der vorgestellten drei Methoden unterstützt, wobei sowohl Luftbilder als auch Nahbereichsaufnahmen verwendet werden können.

1   INTRODUCTORY NOTES

1.1   What does "True Orthophoto" mean

The dautologic term "true orthophoto" (i.e. true correct photo) suggests that the conventional "orthophoto" is something very different which just looks like an orthophoto but actually is not a correct orthophoto. Nowadays, the term true orthophoto is generally used for an orthophoto where surface elements that are not included in the digital terrain model are also rectified to the orthogonal projection. Those elements are usually buildings and bridges. One should be aware that the trueness of an orthophoto is more or less a matter of the scale, and, last but not least, of feasibility. There will always exist object details, that are not correctly mapped (such as trees, cars, very small and less important objects etc). From this point of view the ideal true orthophoto remains a fiction. Whether a pure terrain model is sufficient for the generation of an orthophoto mainly depends on the intended orthophoto scale. The larger the scale, the more objects must be included in the surface model and the more important becomes real three dimensional modelling of the objects. Consequently, one must also not forget, that with the increasing importance of real three dimensional surface modelling the generation of orthophotos, i.e. the rectification of photographs from the perspective projection to an orthogonal projection with a uniform scale will sooner or later become just one special case of a general image transformation.

1.2   DTM, DBM and DSM

Before commencing with details about the generation of true orthophotos a few commonly used abbreviations should be explained here. The DTM (Digital Terrain

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Amhar et al.   17

Model) is an elevation model that describes the surface of the terrain with or without vegetation. DTMs are usually 2.5 dimensional data sets and should, in particular for large scale applications, include breakline and formline information in order to take into consideration terrain discontinuities and thus significantly improve the geometric quality of the resulting orthophoto.

Digital Building Models (DBMs) are intended to describe the surface of usually man-made object details. A real three dimensional representation is necessary leading to a much more complex data structure than generally used for DTMs. A typical DBM of a house, for example, consists of the walls and the roof planes.

The term Digital Surface Model (DSM) has been differently defined by various authors. While DSM is sometimes used as a synonym for DBM, the more logical definition is to use DSM for the representation of the entire surface of the observed region. Therefore, in open areas the DSM is identical to the DTM, in other areas the DSM is either identical to a DBM or a combination of DTM and DBMs. DTM and one or more DBM(s) may concurrently exist at the same geographical position, for instance in cases where a bridge crosses a valley (DTM plus bridge DBM) or where, especially in urban areas, viaducts are built over buildings (bridge DBM plus building DBM plus DTM). The DSM is the ideal complete geometric surface description used for true orthophoto generation.

1.3   Why "True Orthophotos"?

While up to recently orthophotos usually served as image maps in small and medium scales, the increasing importance of GIS, in particular in urban areas, together with the utilization of orthophotos for updating and planning tasks (and not only for visualisation and orientation) disclosed the typical shortcomings of conventional orthophotography to a great group of non-photogrammetric users. Perspective displacements and occlusions make it impossible to superimpose vector data on the orthophotos for checking and change detection purposes. The image content is partly geometrically wrong and/or incomplete. The need and a demand for a complete and geometrically correct image data base can only be fulfilled by true orthophotos.

2   THE GENERATION OF TRUE ORTHOPHOTOS

At the first sight one would suggest to include the top surface of the terrain together with that of buildings in a more complete and refined 2.5 dimensional DTM and start the usual orthophoto process. By looking a bit closer one can easily understand that this simple solution is far from being perfect. The most obvious effect are double mappings in occluded areas that confuse users even more than the displacements of conventional orthophotos (Figure 1).
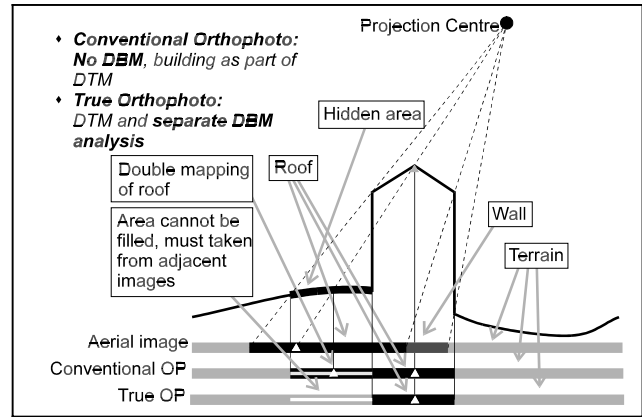

Figure 1: The double mapping problem

The ideal solution must be based on a thorough visibility analysis by tracing the imaging ray from the top of the surface back to the projection centre of the photograph. Only those rays will lead to a rectified image pixel that do not intersect any other object before arriving at the projection centre. Unfortunately visibility analysis might become rather complicated and therefore may significantly slow down the orthophoto generation process. For that reason three different ways are proposed here to obtain a correct orthophoto. Which of the methods is adequate and least time-consuming can easily be decided by a rough visual analysis of the image content:

(1) If the image contains mostly terrain with simple individual houses that do not hide each other, the least sophisticated approach may be used. DTM and DBM are treated independently. The DBMs as three dimensional structures are analysed and correctly rectified, thus obtaining the true orthophoto of the houses that does not contain any image data of the surrounding terrain. In the course of the process one also can mask out those areas in the input image that are covered by houses. This modified input image is then subjected to the generation of a conventional orthophoto that eventually contains the rectified image content of the terrain. Areas where house pixel would usually appear are filled out by the mask value. The final true orthophoto is created by merging the two intermediate orthophotos.

(2) The second approach is very similar to the previous one and should be applied in dense settlements and urban area or where rather complex building blocks that hide each other can be found. The process is basically the same as above with the only difference that a visibility analysis is performed within the DBMs. The remaining process is identical. Both (1) and (2) are two-step solutions.

(3) The previous suggestions work only if the building objects are not occluded by terrain. Therefore, a third method has been provided that covers the treatment of all sorts of occlusions: buildings hide terrain, buildings hide buildings and finally terrain hides buildings. The DTM and the DBM are stored in one common DSM data base and the orthophoto is generated in one step with a complete and thorough visibility analysis.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

18   IAPRS, Vol. 32, Part 4 "GIS-Between Visions and Applications", Stuttgart, 1998
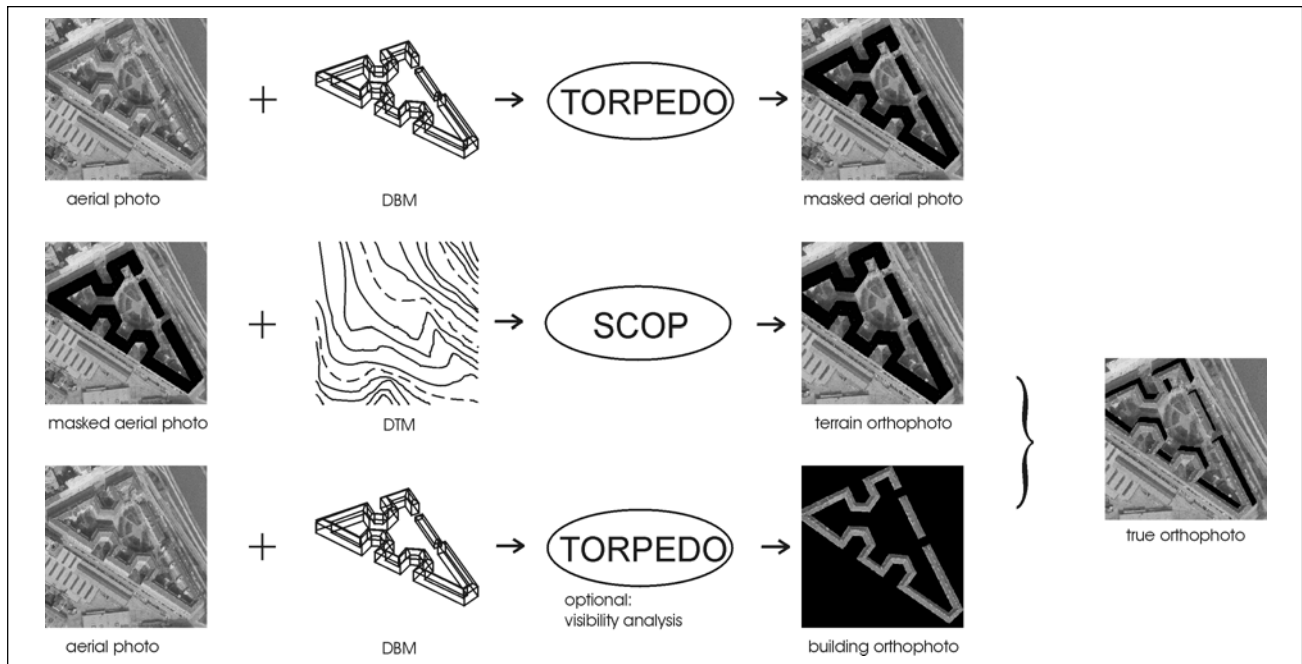

Figure 2: Flow chart diagram of true orthophoto generation

All three variants have been realized in the program package TORPEDO (Three dimensional Object Resource Package for Enhancing Digital Orthophotos), an independent software that works in our case in conjunction with the digital orthophoto program SCOP.DOP (Ecker et al., 1993; Molnar, 1994). The flow chart diagram in figure 2 demonstrates the basic principle of true orthophoto generation through the approaches (1) and (2), respectively.

3   THE DIGITAL BUILDING MODEL

For many cases, in particular for medium scale orthophotos, a simple DBM based on triangles and quadrangles as primitives can be used. The model applied in TORPEDO distinguishes between the plane object face types "walls" and "roofs". "Walls" are vertical planes that will never be mapped in the orthophoto although they can be seen in the original image. "Roofs" are any non-vertical, horizontal or oblique planes on the top of buildings that would be visible in the orthogonal projection (Figure 3) if not hidden by another object above them (e.g. the roof of a building below a bridge will not be visible in the orthophoto although possibly visible in the aerial image).
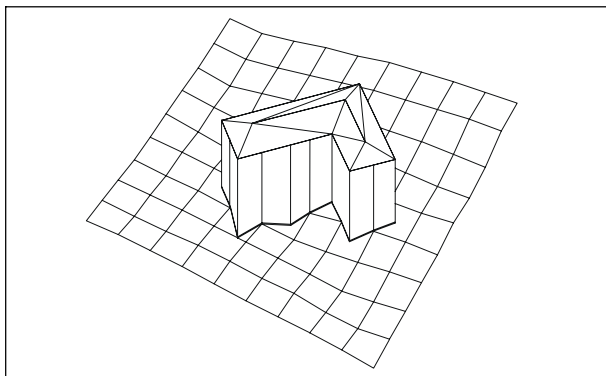

Figure 3: DBM on top of DTM

TORPEDO stores the DBM in a relational data base system with points coordinates, the geometric primitives, the topological relation and additionally so-called identification codes for each geometric primitive. The identification code is a unique numbering scheme that contains the encoded attribute of the face type.

The most time-consuming and cumbersome part of the entire process is currently the data acquisition for building up the DBM. Automatic or semi-automatic procedures based on image matching and/or laser scanning exist (Brunn et al., 1997; Gruen, 1997; Haala et al., 1997), although much research and development are still necessary, especially for urban areas. The approach presented here does not include any data collection methods. We assume, that the roofs have been measured manually in aerial photographs (for instance on an analytical plotter) by digitizing the eave lines and the discontinuities, i.e. the various ridges. We also assume, as a justified approximation in medium scale images, that the eaves are intersecting lines of walls and roof planes. For the generation of the wall elements, one just needs to generate vertical planes through the eaves and intersect them with the DTM. If measured in a sophisticated way a specially adapted triangulation program (Halmer et al., 1996) together with some utilities can be applied that immediately delivers the geometric primitives, their identification codes, their topological information, and eventually the final DBM.

4   THE VISIBILITY ANALYSIS

As mentioned above visibility analysis becomes a crucial part of the orthophoto process if hidden buildings are involved (cases (2) and (3) in section 2). A commonly used method for visibility analysis is the so-called Z-buffer algorithm where a image matrix is used to store for each pixel the distances (Z) between the projection centre and the object surface. TORPEDO employs an extended version, the so-called ZI-buffer.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Amhar et al.   19

The usual Z-image-matrix is complemented by a identification code (=I) of the geometric primitive involved.

The ZI-buffer is generated by projecting each DBM surface polygon into a fictitious image plane with the same resolution and perspective properties as the respective original image and which had been initialized with a predefined background value. The projected polygon is rasterized and each involved pixel is filled with the Z distance and the polygon's identification code but only in cases where the background value has not been overwritten yet and where a possibly already existing Z-value is greater than the current value. Since the identification code enables the program to distinguish between walls and roofs, the resampling process for the orthophoto generation will check the code and will rectify only those pixels whose code is associated to "roof". Figure 4 shows the principle of the ZI-buffer.
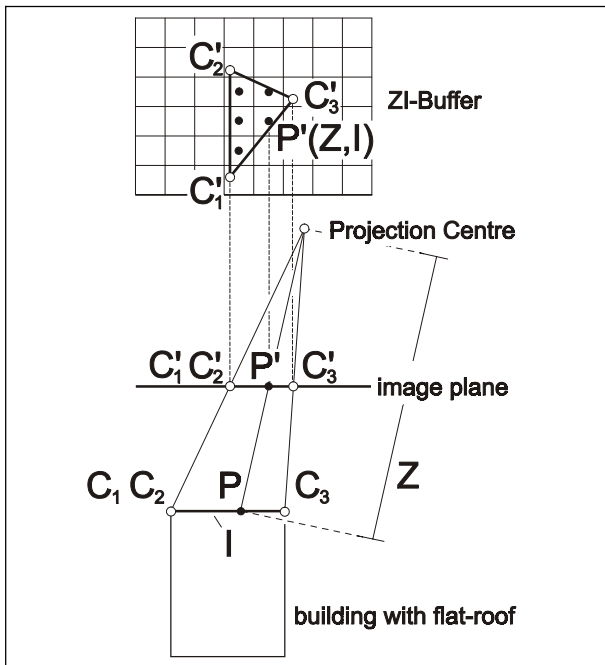

Figure 4: The principle of the ZI-buffer

The ZI-buffer stores distances (four bytes real) and codes (four bytes integer). In case of one band image (with 1 byte depth) the size of the ZI-buffer is therefore 8 times that of the original image. In order to keep the resources as low as possible TORPEDO can limit the extent of the ZI-buffer to a local area that is automatically determined when the individual roof faces of the object are processed. In this way only a rather small sector of the entire image must be stored at once and will well fit in the computer memory. In certain cases the computational effort could be reduced even more (Amhar, Ecker, 1996).

Visibility analysis is rather time-consuming. Especially in method (3) (see section 2) the thorough analysis may essentially slow down the entire process. One should therefore be very careful in the decision whether a complete visibility analysis is absolutely necessary in practice.

5   MERGING AND MOSAICKING ORTHOPHOTOS

5.1   Merging DTM-based and DBM-based orthophotos

The final true orthophoto is obtained by merging the terrain orthophoto and the building orthophoto. This merging process is rather simple in our case and is equivalent to a logical <OR> operation between the two images if the background value has been initialized with greyvalue 0. The resulting image will still contain background patches in all those areas occluded in the aerial image.

5.2   Obtain completeness by mosaicking

Missing image information can be filled in from adjacent images that must have been subjected to the same true orthophoto procedure. In many cases it would be sufficient to process only the missing areas rather than the whole images. (Figure 5)
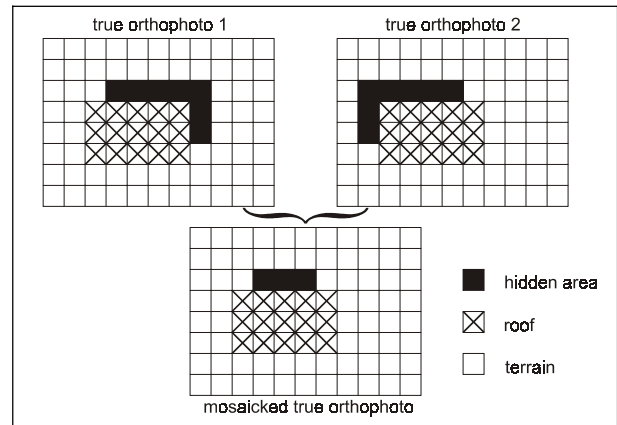

Figure 5: Mosaicking process

The best result as far as the completeness of a true orthophoto is concerned will be reached if the image flight had been carried out with at least 60% sidelap within as well as across the flight strips. Still, there might in certain cases remain unfilled areas even under optimum imaging conditions. If houses are very close to each other, in particular in cities with high rise buildings, then the terrain in between might not be seen by any of the involved photographs and the final orthophoto cannot be filled up with image information in those areas. By using narrow angle lenses one can reduce these effects significantly.

Completing the orthophoto content with the help of neighbouring images is a typical mosaicking problem. Even if we assume an ideal geometric accuracy so that the image contents will fit ideally to each other without any geometric displacement, in many cases the cutlines will remain visible due to radiometric differences between the images involved. This problem is particularly immanent in colour orthophotos. The best results will be achieved if a radiometric adjustment took place before the filling process. One may adjust the original images to each other. The better way is certainly an adjustment procedure in the orthophotos that takes into consideration overlapping image information. For that purpose a complete orthophoto must be generated of all necessary images.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

20   IAPRS, Vol. 32, Part 4 "GIS-Between Visions and Applications", Stuttgart, 1998

Radiometric mosaicking is not included in TORPEDO and may run as an independent process. One just needs to be sure that any involvement of background areas in the radiometric adjustment is inhibited on the one hand, but on the other hand the program must guarantee that background patches are correctly treated even if they are distributed inside the entire orthophoto area. One should be aware that some commercially available mosaicking programs allow a background region only around the image boundary and assume a continuous image in the centre. They treat background values within the image as valid image information and will, therefore, not fill up any holes. Figure 6 shows a detail of a suburban area where a left and a right orthophoto has been merged to yield a true orthophoto. By comparing the same detail with a conventional orthophoto one can clearly see the differences and understand the geometric achievement. Figure 7 is the true orthophoto of a larger area of the same town.
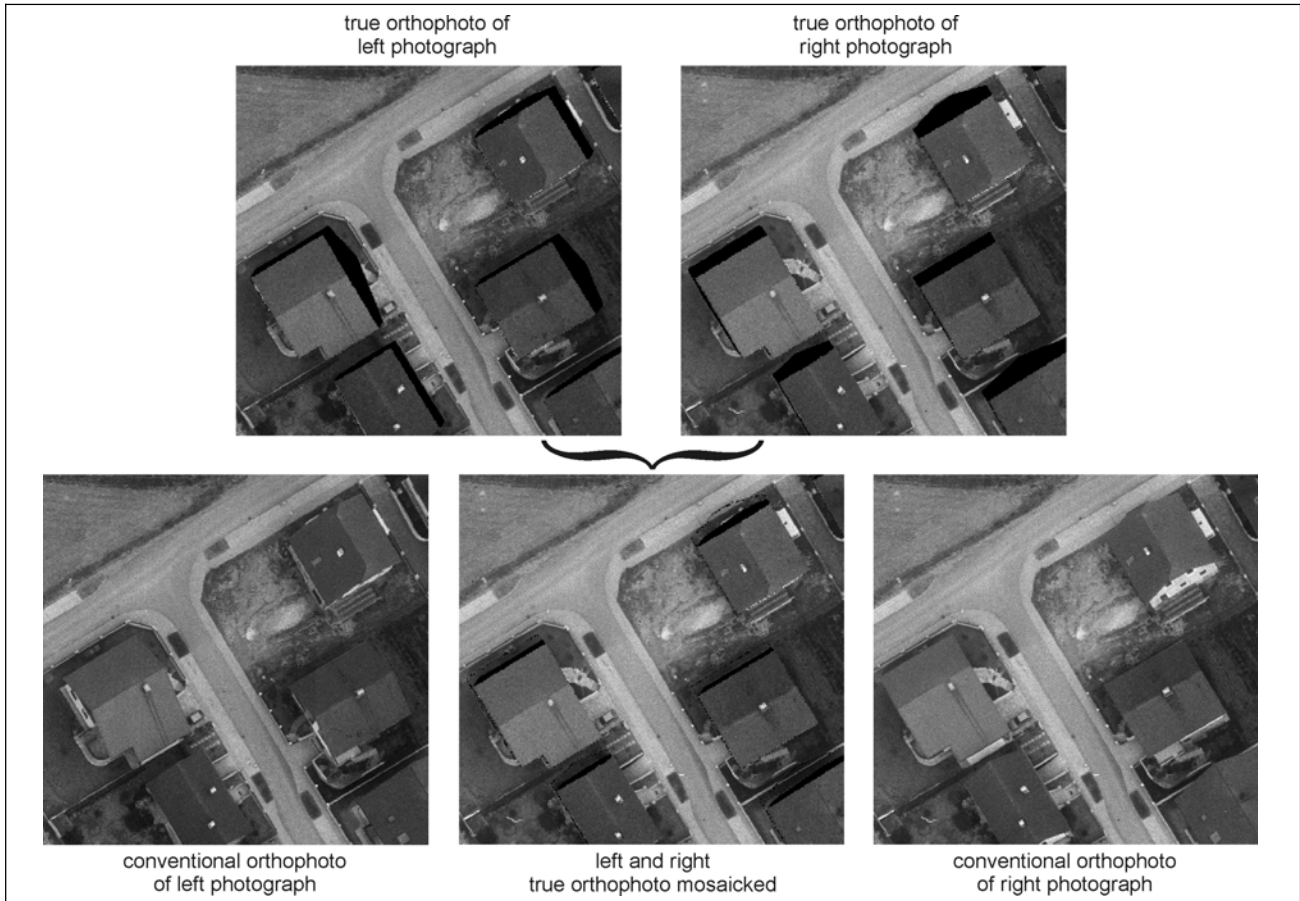

Figure 6: Results of orthophoto generation with TORPEDO in contrast to conventional orthophotos

6   SPECIAL PROBLEMS

6.1   Artifacts along roof boundaries

One of the problems that occur in any case is caused by mixed pixels, rounding effects and possibly also by slight inaccuracies of the building model (due to simplification or inexact roof measurement). Dependent on the geometric resolution and on the contrast between roof and wall or roof and terrain in the original digitized image the roof boundaries consist of mixed pixels with more or less incorrect greyvalues. The larger the pixels and the greater the contrast the more likely are visible artifacts in the true orthophoto either along the roof boundary or on the terrain where the displaced roof lay in the original image. Those artifacts may resemble linear object features (such as fences, walls or walkways) and therefore might lead to mis-interpretation by the user. Unfortunately it is almost impossible to avoid those effects or to automatically detect and remove them other than manually.

6.2   Remaining individual background pixels

Similar effects are caused by rounding problems during the independent calculation of the DBM orthophoto, the DTM orthophoto and those of neighbouring images. After the orthophoto merging process individual background pixels or one pixel wide background lines will remain in the final orthophotos. Though related to the effect described in the above paragraph one can easily remove those pixels with a simple averaging filter that is initiated only on places of background pixels thus filling up the disturbing positions without deteriorating the remainder of the image.

6.3   Smearing effects due to acute ray intersection

When we explained the ZI-buffer method we mentioned that a pixel in the image is classified according to its attribute "wall" or "roof". During the resampling process "wall" pixels will be ignored while roof pixels are rectified. Basically this rule is correct but we could refine

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Amhar et al.   21

our process and thus improve the quality of the resulting orthophoto if we took into consideration the intersection angle between the roof surface and the image ray. Then only roof faces with angles above a certain threshold would be resampled. Smearing, rounding and mixed pixels effects could be avoided to a high extent. On the other hand one must be sure that the eliminated roof face can be replaced from another image in a better way. This check has not been installed yet in TORPEDO.

7   CONCLUDING REMARKS

7.1   Close range applications

A very challenging application is the ortho-rectification of building facades for architectural purposes. Conventional facade plans are very often rectifications to an average plane or the most prominent plane of the building facade. For many historic houses with intricate decorative elements the simple way of rectification must always be only a rough approximation with lots of displacements at the ornaments. With TORPEDO as true orthophoto tool it is possible to generate a correct facade plan where each detail is placed geometrically on its right position. For close range application the third proposed approach ((3) in section 2) will certainly be more appropriate in many cases.

7.2   Summarizing comment

Practical examples demonstrated the potential of TORPEDO. Urban and suburban areas as well as facades can be rectified successfully. Since a universal solution with complete visibility analysis is very time-consuming TORPEDO offers additionally two simpler approaches that, fortunately, can be applied to most cases in practice. Independent of the orthophoto program the true orthophoto process has a few minor shortcomings, that are mainly caused by mixed pixel and that cannot be avoided or eliminated automatically. The great advantage is the geometric correctness that allow superimposition of vector data and intergration into a GIS without disturbing contradictions due to perspective displacements of buildings.

Whether the true orthophoto generation is economically efficient or not depends predominantly on the effort that is necessary to create the DBM. If a DBM already exists (at least to a high extent) in a GIS data base, the costs will be inessentially higher than those for a conventional orthophoto. If a DBM is not available it can be created in a rather simple way by measuring the roof elements, such as ridges and eaves, of buildings. Then a primitive house model can be automatically generated by a utility program. The examples presented here prove the suitability of such unsophisticated DBMs for medium scale applications.

8   REFERENCES

Amhar F., Ecker R., 1996: An integrated solution for the problem of 3D man-made objects in digital orthophotos. International Archives of Photogrammetry and Remote Sensing, Vol. XXXI/B4, pp. 84-89.

Amhar F., 1997: A contribution to geometrically correct digital orthophoto under consideration of general 3D objects and its realization in a software package. Doctorate thesis, Vienna University of Technology, 129 pages.

Brunn A., Weidener U., 1997: Extracting buildings from digital surface models. International Archives of Photogrammetry and Remote Sensing, Vol. XXXII/3-4W2, pp. 27-34.

Ecker R., Kalliany R., Otepka G., 1993: High quality rectification and image enhancement techniques for digital orthophoto production. Photogrammetric Week '93, Wichmann Verlag, Karlsruhe, pp. 142-155.

Gruen A., 1997: Automation in building reconstruction. Photogrammetric Week '97, Wichmann Verlag, Karlsruhe, pp. 175-186.

Haala N., Brenner C., Anders K.-H., 1997: Generation of 3D city models from digital surface models and 2D GIS. International Archives of Photogrammetry and Remote Sensing, Vol. XXXII/3-4W2, pp. 68-75.

Halmer A., Heitzinger D., Kager H., 1996: 3D-surface modeling with basic topologic elements. International Archives of Photogrammetry and Remote Sensing, Vol. XXXI/B4, pp. 407-412.

Molnar L., 1994: The program system SCOP. Product Information, Institute of Photogrammetry and Remote Sensing, Vienna University of Technology.

Figure 7: Merged and mosaicked true orthophoto of a suburban area