FUSION OF 2D GIS DATA AND AERIAL IMAGES FOR 3D BUILDING RECONSTRUCTION

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Commision III, Working Group III/2

KEY WORDS: Fusion, 3D GIS, 3D Urban Database, Aerial Photogrammetry, Affine Matching, Roof Skeleton.

ABSTRACT

We present a method to reconstruct roofs of a cities' buildings. The algorithm is based on a fusion process and exploits aerial image data and the existing 2D GIS and DTM data. Special attention we offer to the 2D roof skeleton, which is developed from the fusion result. The footprint of the building and the roof outline, which is part of the roof skeleton, are merged and create the building box.

KURZFASSUNG

Der Beitrag befaßt sich mit der Rekonstruktion von Dachformen im Stadtbereich. Luftbilder und Daten des bestehenden 2D GIS sowie Geländehöhen (DTM) werden gemeinsam genutzt. Spezielle Aufmerksamkeit widmen wir dem 2D Dachskelett, das aus dem Fusionsprozeß der Quellendaten entsteht. Gebäudegrundriß und Traufenlinie (ein Teil des Dachskeletts) bilden gemeinsam die Gebäudegrobform ("building box").

1 INTRODUCTION

Automated recognition and reconstruction of objects from images is one of the most important tasks in the ongoing development of computer vision and object reconstruction disciplines. Not at least it is an issue if the new skills and tools of these working areas are used to enhance and improve the procedures of automated mapping and documentation of the environment [Förstner, Pallaske, 1993]. In the case of urban data acquisition and administration we are now going towards fully 3D models of towns and need to improve our methods to increase the output and the quality of a modern and powerful mapping and modelling procedure [Leberl et al. 1994], [Gruber et al. 1995a].

Beside others we have focused on the reconstruction of buildings from aerial images and the exploitation of the existing knowledge from other data sources like the 2D GIS [Gülch, 1992], [Lang, Schickler 1993], [Haala et al. 1994]. This leads to a fusion process, which creates the basic relationship between aerial images and the footprint of buildings, as it is available from the digital map [Gruber et al. 1995b]. We present the key functions of our procedure and show the tools and algorithms we use for the detection and reconstruction of roofs of buildings. The height of the detected roof-outline and the known terrain elevation leads to a simple description of the entire building, the so-called building box. This initial 3D data set of the entire object shall be used for further processes like the enhancement of geometrical detail. Finally we have to add the phototexture from images to the geometry of the CAD model. This task, which has to be done to involve the sterile geometry towards a bright and well-rounded database for various usage will be supported by image data, which have already been involved in our procedure.

2 MODELLING CITYSCAPES

The establishment of fully 3D models of urban environment seems to be the next and unavoidable step in improving the data for the management of our growing cities. The 3D data will not only present the geometric relationship of objects, but also permit to create photo-realistic renderings for various decision making and training tasks. Today we are able to exploit powerful computers and strong software to create such databases by hand. We have systems to handle the source data (e.g. photogrammetric workstations like DPWSs to set-up image data and to do stereo restitution), to merge and refine data (e.g. 3D CAD systems) and we have software to brush up and enhance phototexture (like Photoshop from ADOBE).

There is no doubt, that ongoing work has to concentrate onto methods and strategies to increase the throughput of the entire modelling process. We are sure that there is not only one field of interest where improvement urgently needs to be done. Table 1 shows a number of different activities, which are key members of the modelling process for Cybercities. The amount of labour based on experiences during manual modelling and the promise of automation (5=heigh, 1=low) is estimated. In addition we show which type of equipment is used during each activity. From Table 1 we see that texture processing and texture mapping needs about half the cost of labour within the total procedure. This may feed arguments against textured models, which we easily contradict by comparing costs and benefits of the phototexture. We have also take into consideration that one single part of the entire process is not stand-alone but will gain from adjacent development (e.g. the automation of the texture mapping will be influenced by object reconstruction procedure, if digital image data are source data of both, the geometry and the texture).

In the current contribution we pick out a specific task of

Task	Labour %	Automation	Workstation
Source data acquisition	5	3	Cameras, MIS, 2D GIS
Source data preparation	5	5	film scanner, PAS, 2D GIS
Photogrammetric set–up	10	3–5	DPWS
Reconstruction of objects	20	3	DPWS + 3D CAD
Texture processing	25	2	TPT
Texture mapping	25	4	3D CAD
Tuning and visualization	10	–	GWS

MIS = Mobile Imaging System
PAS = Picture Archiving System
DPWS = Digital Photogrammetric Workstation
2D GIS = 2D Geographic Information System (incl. DTM)
3D CAD = 3D CAD System
TPT = Texture Processing Tool
GWS = Graphics Workstation

Table 1: Key processes of a modelling procedure for Cybercities

object reconstruction, namely the reconstruction of roofs of cities' buildings. The main source data is a set of digital aerial images, providing multiple overlap and the possibility of stereo restitution. We also involve the existing 2D GIS, i.e. the digital map. We take in account, that existing 2D GIS data, which are currently maintained by cities' administrations have to be involved because of their technical existence and their legal charakter [Wilmersdorf 1994]. The fusion process we are investigating, is based on an affine matching procedure, which allows to relate line features of the map, i.e. the footprints of buildings and the line features derived from digital images. From this first solution - the overlay of the detected roof outline on the digital image - we proceed to detect and refine the shape of the roof and details like chimneys and attic windows.

3 FUSION OF MAP AND IMAGE DATA

The first step of our fusion process of image-based and map-based data consists of the classification of the resulting objects, i.e. buildings with respect to the type of source data (cf. Figure 1 and points below) and to the degree of quality of the resulting geometrical model of building (cf. Figure 2 and points below).

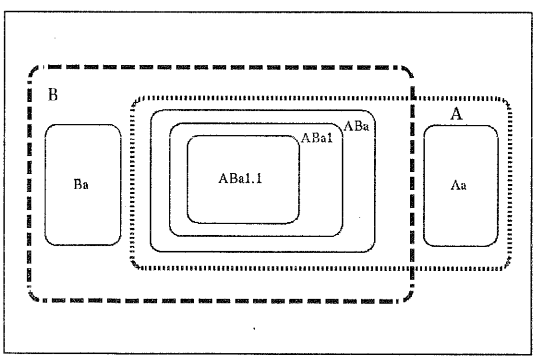

Figure 1: Relations between buildings in GIS (group A) and on aerial image (group B).

- A - all GIS buildings,
- Aa - GIS buildings, which don't exist in aerial images,
- B - all buildings in aerial images,
- Ba - buildings, which don't exist in the digital map data set, but can be reconstructed using parametric 3D roof skeleton database or using other methods,
- ABa - GIS buildings with reconstructed roof outline.
- ABa1 - GIS buildings with reconstructed 3D roof skeleton,
- ABa1.1 - GIS buildings with reconstructed 3D roof detail.

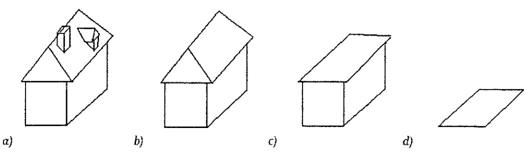

Figure 2: Types of reconstructed buildings.

- a) - 3D building box, roof skeleton and roof detail [ABa1.1],
- b) - 3D building box and roof skeleton [ABa1],
- c) - 3D building box [ABa],
- d) - 2.5D building's footprint (GIS + DTM) [A-ABa].

Other steps are documented and enumerated within the following paragraphs and depicted by figures:

3.1 Preparation of the image source data.

The source image data may be analog and need to be digitized via a film scanning system. In this case we have to chose the appropriate pixel size and the radiometric resolution of the digital data. Initial set-up data and photogrammetric parameters are necessary to relate the image data to the world coordinate system. The digital image data is now filtered with low-pass filter, processed by edge detection algorithm and converted into so-called tokensets of lines [Burns et al. 1986] (cf. Figure 3).

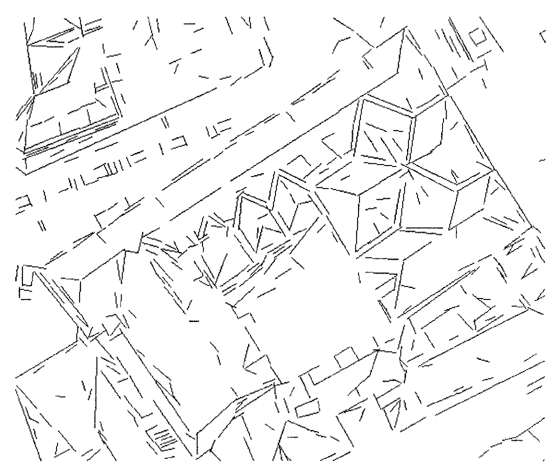

Figure 3: The line-segment tokenset as input-data for determination of roof-skeleton.

3.2 Preparation of the digital map.

The existing data set of the 2D geographic information system of the city shall be used to extract the footprint of each building. We may use in addition "Number of floors of building" as an attribute for coarse determination of roof outlines' elevation above the terrain surface.

3.3 Fusion of image data and digital map (Monocular approach).

The tokenset of the digital image and the building's footprint are now related one to another by a piecemeal affine matching procedure (cf. Figure 4). The idea is based on affine matching proposed by [Pinz et al. 1995] and is applicated successive for "pieces" of coarse roof outline - one line segment and two neighbours. For this case we can generalize perspective to affine transformation. The start values for this procedure are extracted from the set-up data of the aerial photograph and the known coordinates of the map data, combined with at least approximate elevation data of the ground and approximate knowledge of the height of the building. Results of the matching procedure of GIS-building's outline and Burn's lines are presented in Figure 5.

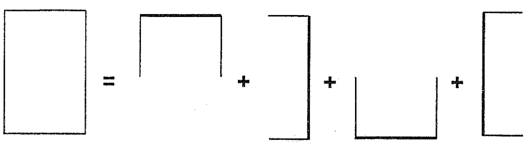

Figure 4: Four steps of piecemeal affine matching in the case of a rectangle (4 lines outline).

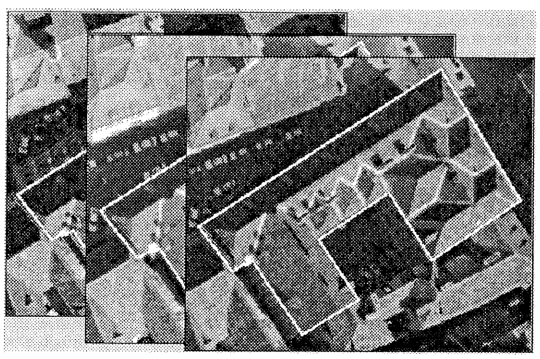

Figure 5: Results after piecemeal affine matching (based on distance transformation) between GIS-building's outline and Burn's line segments.

3.4 The 3D roof skeleton (Stereoscopic approach).

The results of the fusion process are enhanced and verified by the involvement of a second image, which allows a stereoscopic investigation of the scene. Starting from the extracted outline of the roof we create a fully three-dimensional set of roof lines, which we call the roof-skeleton. This data set has to be topologically checked and finally leds to the CAD-model of the entire roof. A number of different steps of the procedure is presented in Figure 6 and 7.

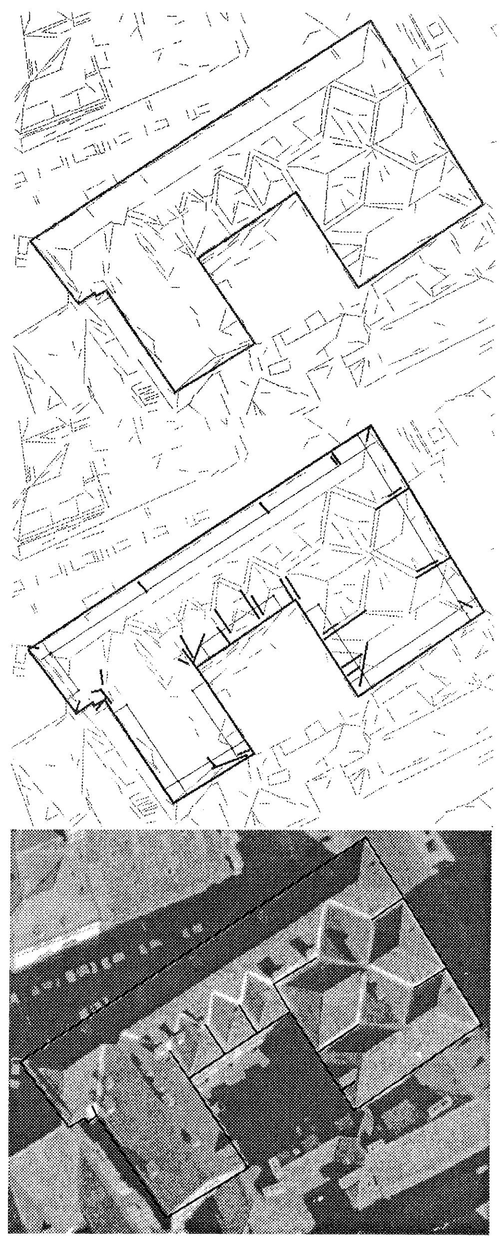

Figure 6: Different steps of the extraction of the roof skeleton based on image data and 2D GIS (6a, 6b, 6c).

4 RESULTS FROM TEST SITE GRAZ

The medieval roofs of downtown Graz give us the background of a suitable test site for our investigations. Various details and subdivided roof shapes measure the quality of our approach. The current result of the algorithm we are working on is depicted in Figure 6.

From the token-set of lines in Figure 3, derived from digital image data we start to extract the roof outline (6a) and exploiting hypothesies of angularities between roof outline, ridge lines and other edges of the roof we create the roof skeleton step by step (6b,6c,7a,7b) (cf. parsing in [Stokes, 1992]). The final result, which needed a small amount of manual interaction is compared with the digital image of the scene (7c).

5 FURTHER INVESTIGATIONS.

The result of our procedure may be understood as an initial step towards automated roof reconstruction, which needs to be expanded and improved. A multi-image approach shall be one of our further investigations. This may cause a better accuracy by means of least squares adjustment, available from multi-stereo solutions. Beside the improvement of the quality of the derived roof skeleton, we have to increase the level of detail of the CAD-model by means of detection of chimneys, sky-lights and other small parts of roofs. This is a must if phototexture is involved to enhance the CAD-model of the roof in order to guarantee the correspodence between phototexture and geometry [Gruber et al. 1995b].

We also intent to show, how a verification process of the automatically derived CAD-model of the roof may be lead by image processing methods. This means, that the correspodence between CAD-data and texture-data may be exploited to serve as a tool for reviewing and testing.

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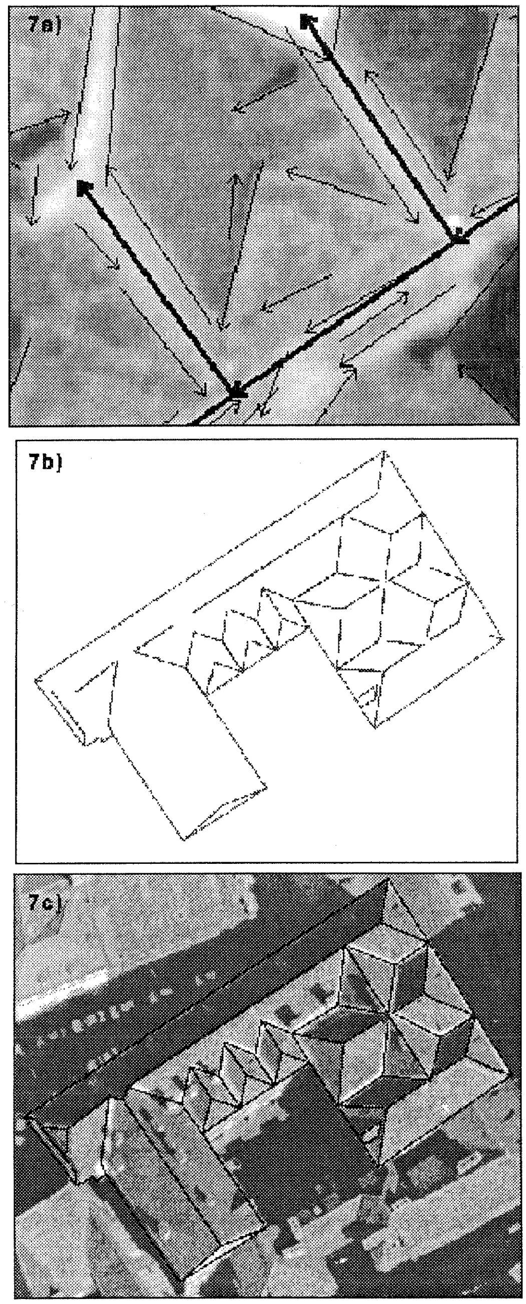

Figure 7: Further improvements of the roof skeleton.