FUSION OF 2D-GIS AND IMAGE DATA FOR 3D BUILDING RECONSTRUCTION

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ABSTRACT

This paper addresses the issue of extending preexisting two–dimensional geometric data representing the ground plans of buildings to three–dimensional descriptions by the combination of this data with the analysis of aerial images. Frequently, ground plans have already been registrated and represented either analog in maps and plans or digital in a Geo Information System (GIS). Within the article the utilized ground plans are exemplary provided by a digital cadastral map, which is assembled as an area covering data base and at the moment is available for 40 % of Germany. Even though this information is very valuable for the 3D building reconstruction, the available data structures contained in the GIS have to be expanded considerably until they can be used to support the interpretation of images. In general the available information has to be transformed into more complex structures, which are more suitable and knowledge on how to use this information has to be provided. This implies steps like the extraction of relations which are only contained implicitly in the available data, the elimination of unnecessary information (e.g. details not visible in aerial images) and the generation of hypotheses on the missing 3. dimension of the represented building. These hypotheses the can be verified and the unknown parameters can be determined by the analysis of the aerial images.

1 INTRODUCTION

At present most GIS products and also authoritative GIS use a flat surface (planimetry) as spatial reference and therefore only provide 2D data structures. Nevertheless there is a clear trend towards systems which are able to represent, manage and analyze 3D information. An example for the growing number of applications of this kind of data are 3D urban models; simulations and visualizations demanding three-dimensional descriptions of build-up areas have become standard applications for planning purposes in urban regions. Objects mainly relevant for the description of these areas are Digital Terrain Models (DTM) and man-made objects like buildings, roads or other supply facilities. This article will concentrate on the acquisition of three-dimensional building reconstructions.

The data capture for that purpose is frequently done by analyzing aerial imagery, since photogrammetric data is three-dimensional, exact, largely complete and up-to-date. Because manual interpretation is very time consuming, a lot of effort has been spend to speed up this process by automatic or semi-automatic procedures. Even though the use of aerial imagery as mere database for automatic reconstruction of the three-dimensional building geometry is sufficient in principle, especially while aiming on fully automatic procedures considerable progress can be achieved if additional information is used. One reason for the actual problems of automatic image interpretation is the great amount of (partly irrelevant) information contained in images. Grey-values are influenced by a large number of factors, e.g. object geometry, shadows, texture and reflections. This frequently makes it difficult to separate between irrelevant details and important information, which is required for a task like the automatic reconstruction of objects from images. Nevertheless, the three-dimensional reconstruction of quite complex objects like buildings can be improved considerably if image data is combined with other data sources. One example is the additional use of height data. Since height data is independent from illumination or surface material the extraction of the required geometric information and therefore the interpretation of this kind of data is easier compared to image interpretation. By a combination of both data sources their specific strengths – relatively simple interpretation of height data on the one hand, great content of information, richness of detail, high resolution and accuracy of image data on the other hand – can be utilized (Haala 1995) . This article aims on the combination of image data and preexisting *two-dimensional* ground plans of buildings to capture *three-dimensional* reconstructions of buildings. The use of information, which is supplied by a GIS is also motivated by the fact that due to the growing number of already existing databases, apart from the initial data acquisition, the upgrade, completion and extension of these existing databases will become an aspect of growing importance.

In the following chapter available data sources, which can be used for 3D building reconstruction will be described. In order to integrate this 2D data into the automatic image interpretation, in the first processing step the used data has to be expanded e.g. by the extraction of rela-

Figure 1: Digital cadastral map

3 GENERATION OF 3D HYPOTHESES

A system for 3D object reconstruction consists of two major components, the *object modelling* or generation of object representations and the *matching* of these stored representations to descriptions derived from the sensed images. The model database should contain representations of objects the system is expected to recognize. Our goal is to use the information given in the digital cadastral map to define a 3D model, which can be used for the following image analysis.

3.1 Object Models

Images are two–dimensional representations of a three–dimensional world. Due to occlusion and the perspective view or also caused by lack of contrast, a certain amount of object information is always missing. On the other hand, images contain a lot of information, which is not relevant for a specific task. Only by the use of a priori knowledge on the sensed objects, which is represented by a object model, important information can be separated from irrelevant details and missing information can be completed.

Object models can be classified in two main groups. *Specific models* are descriptions completely and in detail representing a unique object. An example are objects represented in a CAD system by fixed geometry and fixed topology used for tasks like object recognition. *Generic models* on the other hand are used to represent classes or groups of similar objects. An example for this kind of model are *parameterized models*, permitting the representation of objects by fixed topology but variable geometry (Braun, Kolbe, Lang, Schickler, Steinhage, Kremers, Förstner & Plümmer 1995). These models contain all primitives of a certain object class without defining the parameter values. Length, width and height of a quader type object are free, but the number of its points, lines and faces as well as their relations like paralellity of lines or coplanarity of points are fixed. For this reason, a quader is a generic model, capable to represent a whole group of objects.

In principle models for 3D object recognition can be adapted quite well from preexisting CAD-like descriptions of the visible objects (Flynn & Jain 1991). Even though a 3D building model can not be derived definitely from the existing two-dimensional ground plan, the existing GIS data can at least be used to provide a first hypothesis of the 3D shape of the building. Assuming parameter values for the (unknown) roof slope a building of a certain (also unknown) height, which are e.g. dependent on the given usage of a building, the model lines defining the eaves and ridges of a roof can be constructed. For this type of model the parameters referring to the ground plan are fix (e.g. length and width of the building), while other parameters referring to the third dimension (e.g. roof slope or height of the building) are free and therefore will have to be determined by image analysis. For this reason a model generated using an existing ground plan can be interpreted as a mixture between a specific and a parameterized model, since some parameter values are fixed and some parameter values are free.

3.2 Analysis of GIS data

Main goal while analysing the existing digital cadastral map is to select or even create a suitable 3D building model which is required for the object reconstruction by image interpretation. This task implies steps like the extraction of relations which are only contained implicitly in the available data, the elimination of unnecessary information (e.g. details not visible in aerial images) and the generation of hypotheses on the missing 3. dimension of the represented building. Therefore the analysis process split up into the *generalization*, i.e. the simplification of the given contour lines and the combination of adjoining ground plans, and the *construction of buildings*.

3.2.1 Generalization

In order to eliminate details not visible in the aerial images and to simplify the verification process the shape of the ground plans extracted from the digital cadastral map has to be generalized. If e.g. a building is covered by a saddle roof at details of the given ground plan e.g representing bays or ledges will be hidden. Therefore we use the assumption that the 2D contour of a saddle roof can be defined by a rectangle which approximates the shape of the given ground plan.

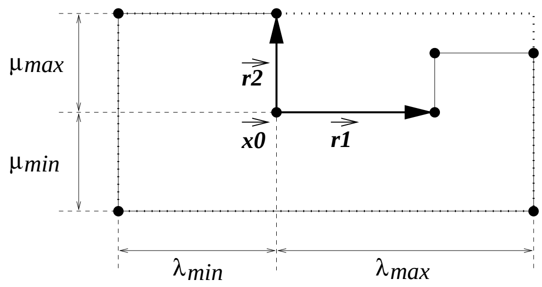

Figure 2: Generalization of a ground plan

The rectangular contour of a saddle roof can e.g. be created by a structural analysis (symmetry, similarity, closeness, unity, continuation) of the given ground plan. For that purpose length and parallelism of polygon edges are the most important features. The longest polygon edge of a given ground plan can e.g. be used to adjust the longest side of a roof. Parallel lines in the ground plan can be used to build a set of rectangles which can be grouped together (elimination of overlapping areas of the rectangles) to find the best representation with rectangles. We use a very simple approach to create a rectangular representation of a given ground plan:

1. Find a right-angled corner in the given polygon **P**. Only if a right-angled corner exists, the polygon is generalized to a rectangle. The selected corner represents the base of a two-dimensional coordinate system as shown in figure 2. Now each point of the given polygon can be described by the following equation :
$$\vec{p_i} = \vec{x}_0 + \lambda_i \vec{r}_1 + \mu_i \vec{r}_2 \quad (1)$$
2. In order to determine λ_{min}, λ_{max}, μ_{min} and μ_{max} all points $\vec{p_i} \in \mathbf{P}$ are inserted in equation (1) to calculate the minimum and maximum values λ_i and μ_i. The points
$$(\vec{p}_{\lambda_{max},\mu_{max}}, \vec{p}_{\lambda_{min},\mu_{max}}, \vec{p}_{\lambda_{min},\mu_{min}}, \vec{p}_{\lambda_{max},\mu_{min}})$$
then represent the required rectangle.
3. The overlap between the constructed rectangle and the ground plan can be used as measure on the goodness of the approximation.

Because the ground plans of the digital cadastral map describe properties, one physical building can be represented by two or more adjoining ground plans, if the building is owned by more than one party. Especially if the grouped ground plans can be represented by a rectangle, it is very likely that they are covered by one common roof. Therefore adjoining ground plans are detected by searching for line segments in the digital cadastral map which are used by different polygons.

3.2.2 Construction of buildings

The creation of a 3D building is a task that cannot be solved in a definite way because besides the unknown height values there are many possible types of roof shapes, e.g. desk, flat, saddle or hipped roofs. Because the usage of a building provides a good hint on the possible type of

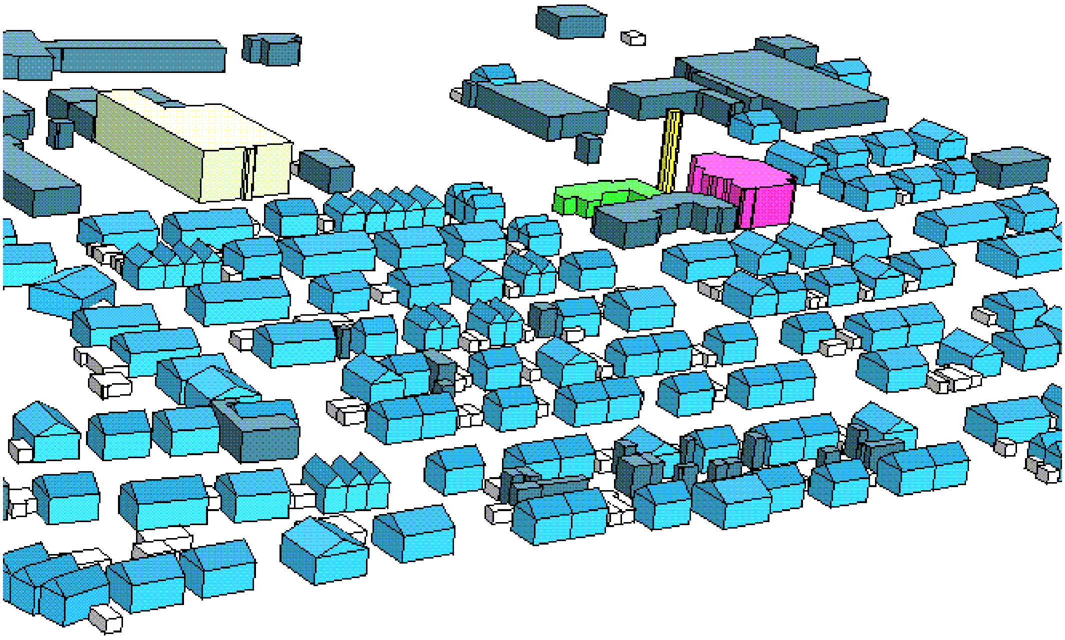

Figure 3: 3D building hypotheses based on the digital cadastral map

roof, the buildings are classified (e.g. garage, residential building, office block, industrial building, church, tower) by analysing the text information contained in the digital cadastral map. Frequently industrial buildings and garages have a flat roof. Since the shape of a desk or flat roof will follow the shape of the ground plan for most cases, the 2D contour line of the roof is assumed to be identical to the given ground plan for these types of buildings. In contrast to that saddle roofs were expected for residential buildings. For theses buildings the generalization process described in the preceding section was applied to define the contour lines of the roof. At the moment the generation of 3D hypotheses and the verification process described below can only handle models of saddle and flat roofs. Even though desk, flat or hipped roofs can be considered as special cases of saddle roofs, other models which are able to cope with modifications of the used rectangular shape will have to be implemented. The ridge lines of the saddle roofs are defined by the longer middle axes of the rectangles, which were generated by the simplification and combination of the given ground plans.

Generally the direction of the ridge of a roof also follows rules of town planning, adjoining buildings e.g. have the same ridge direction, or rows of buildings parallel to a street have ridge lines that are adjusted to the direction of the adjacent street. To make use of this knowledge future work will have to perform further analysis of the given 2D data e.g. by the detection of neighbourhood relations for buildings or by additionally extracting information about streets, which is also contained in the digital cadastral map in form of text symbols.

Hypotheses about other parameters like the height of a building can only be generated by using of *meta-information* that is not given in the digital cadastral map. Such kind of information is the location of the buildings in the city (e.g. city center, outskirts, industrial area) and the knowledge about typical heights or numbers of floors of different kinds of buildings (industrial building, church, garage, office block) dependent on the location in the city. The 3D building hypotheses shown in figure 3 were generated using the generalized ground plans; to define the unknown parameters in height knowledge on the usage of buildings (e.g. garage, residential building, office block, industrial building, church, tower) which was extracted from the digital cadastral map was utilized. To perform the 3D construction the following assumptions on the height values were made:

- Garages : 3 m
- Residential building and office block : 9 m for the ridge, 6 m for the eaves
- Industrial building : 15 m
- Church : 12 m
- Tower : 25 m
- Kindergarten : 5 m
- others : 7.5 m

Because the constructed buildings are only based on quite weak assumptions, a verification process including additional information is necessary. For that purpose aerial images are used.

4 VERIFICATION

To verify the generated 3D building hypotheses and to determine the unknown parameters of the object model, additional information is required. In our approach linear features are extracted from an aerial image and matched against lines of the object model to provide that missing information.

4.1 Feature Extraction

Most existing procedures for building reconstruction make use of the assumption that buildings consist of a number of straight three-dimensional lines and therefore apply linear edge segments as initial primitives to a matching process. We use straight grey-value edges, which are extracted by an algorithm proposed by Burns, Hansen & Riseman (1986) from aerial images of known exterior orientation as primitives of the image description.

Figure 4: Image section with projected ground plans.

For the verification of the generated 3D building hypotheses and the determination of the unknown parameter values, the extracted grey-value lines have to be matched against the corresponding lines of the building model. In order to define possible correspondences between image and model lines, the knowledge on the position of buildings in a global terrain coordinate system, which is provided by the GIS in addition to the 2D shape of the buildings can be utilized. To determine these correspondences the object model and the extracted image primitives have to be transformed into a common coordinate system by perspective transformation. For that purpose e.g. grey-value lines can be extracted from a stereo image pair of known exterior orientation to determine the lines in 3D by stereo matching. Alternatively, terrain heights are required in addition to the 2D coordinates of the ground plan. In order to acquire these terrain heights, existing Digital Terrain Models can be used, which are available for many developed countries. A DTM can also be computed by standard procedures of digital image matching. Problems in build-up areas occurring quite frequently due to occlusions and height discontinuities while applying these image matching techniques can be avoided if the supplied GIS data and a approximate DTM is used to mask out building regions during the matching process. For our purpose it was sufficient to use a DTM provided by the State Survey Office of Baden–Württemberg (Fed. Rep. of Germany). The accuracy of this DTM is in the order of 0.5 m for flat and 10 m for mountainous regions.

Figure 4 shows the ground plans extracted from the ALK, which were generalized and projected to the aerial image using this authoritative DTM as data source to define the required terrains heights.

4.2 Matching

An example for a constructed building, which could be verified by matching a 3D hypothesis against the extracted image description is given in figure 5. The white wire frame shows the initial guess for the building. Therefore the ground plan of the buildings were extracted from the GIS data base and projected to the image using terrain heights provided DTM of the survey authority of Baden–Württemberg. To construct the building the eave lines were assumed to be 6 m, the ridge lines to be 9 m above the terrain surface.

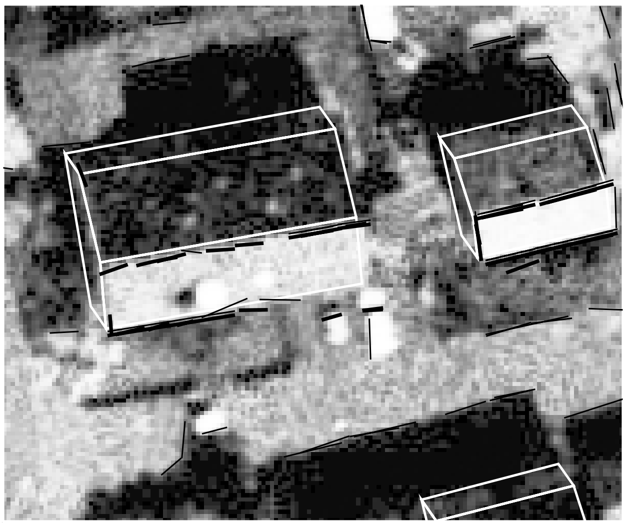

Figure 5: Constructed 3D building hypotheses projected to image (white) and matched image lines (black)

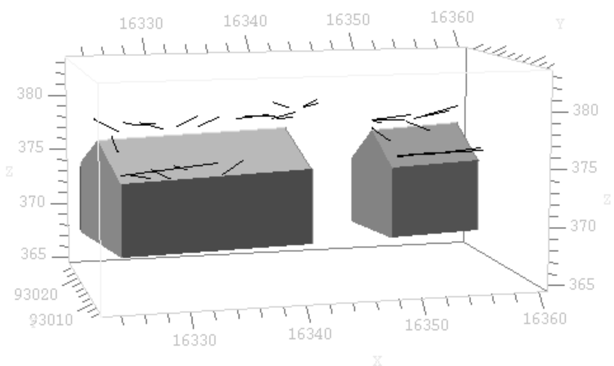

Figure 6: 3D view of building hypotheses and matched image lines

Straight grey–value lines are extracted from the image by the algorithm of (Burns et al. 1986) and matched against the hypothesized roof lines. Assuming that image coordinates of these roof lines and the corresponding image lines only differ from each other due to the deviation of hypothesized roof height and true roof height, the radial distance (distance in direction to nadir point) between the corresponding roof and image line can be used to compute their difference in height. Figure 6 shows the situation of figure 5 as a 3D view with matched image lines and the buildings constructed using the 2D ground plans and the assumed height parameters. After the matched image lines have been determined in 3D, the hypothesized height and slope of the roof can be adopted by a least squares adjustment. Even though it is possible to use a single image for the verification task, it is fraught with meaning to add at least information extracted from a second image to get results which are more reliable. This second image will always be available if an aerial image flight was carried out.

5 CONCLUSION

Within this article we discussed and presented first results of a procedure aiming on the 3D reconstruction of buildings by combing preexisting outlines of buildings and image data. To generate hypotheses for the 3D shape of buildings the ground plans extracted from a digital cadastral map were generalized the combination of adjoining ground plans and the simplification of the contour lines. The information on the use of the buildings also available from the digital cadastral map was utilized to define the unknown height parameters of the buildings. The hypotheses generated by analysis of the 2D data base then were verified by matching lines which were extracted from an aerial image against the lines of the hypothesized building model. Because the building 3D hypotheses can be projected into image space using terrain heights, which are e.g. provided by an existing authoritative DTM, in principle a single image can be used for the verification process, like it was carried out in this article. Nevertheless in our opinion it will be necessary to use at least two overlapping images to increase the reliability of the verification and parameter estimation process.

Image interpretation is far from being solved in complex areas like build–up regions. Nevertheless it is very promising to support this process by additional information like the used 2D GIS data. Moreover, due to the increasing number of already existing digital data, in our opinion the automatic extension and upgrade of these data bases like was is demonstrated in this article will become a topic of growing importance for future applications.

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